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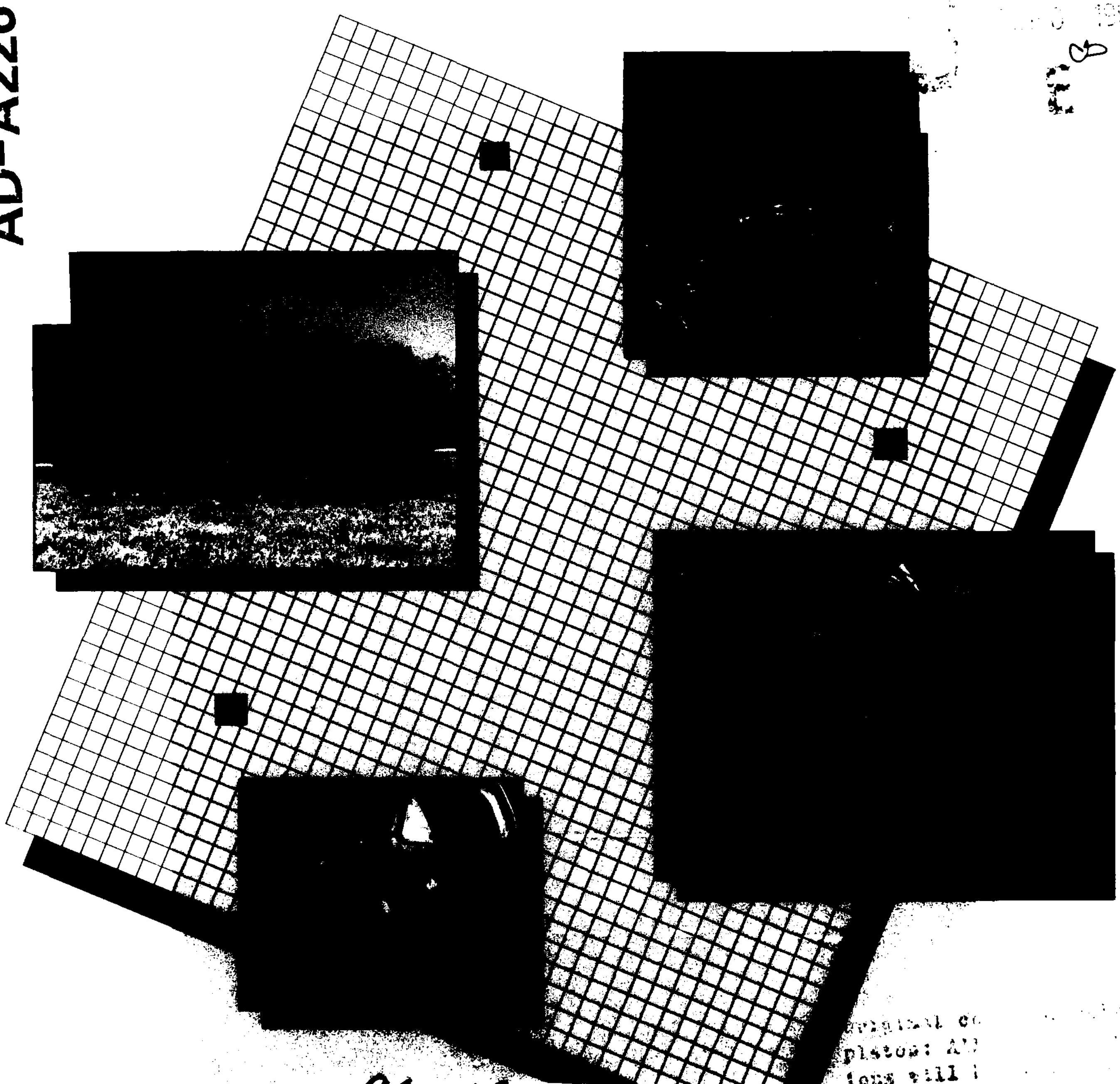
ARMY PHASE III

Small Business Innovation Research Program Review



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ARMY PHASE III

Small Business Innovation Research Program Review

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Prepared for the United States Army, Washington, DC 20301

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Welcome to the Army SBIR Accomplishments Book. We are proud to present a snapshot of Army-sponsored projects which have led to Phase III funding from other Army programs or from industry sources. It takes several years to successfully market good technology, even in a military mission. In some instances, we have found that valuable contributions could not be reported here for contractual or national security reasons.

Given these constraints, our focus is on projects initiated in the 1985 and 1986 solicitations. The first two years of the program, 1983 and 1984, were covered by an Office of the Secretary of Defense study completed in 1989. Four of these early projects are included here because of their significance to Army programs.

We concentrated only on Phase II companies who could prove Phase III success. There were 159 Phase II projects from 1985-1986 programs. Twenty one are included here as definitive success stories significantly helpful to Army/DOD missions. We congratulate those companies and the Army Project Managers who monitored this research. We strongly encourage other Army SBIR contractors to help us continue to improve Army SBIR research and to participate in planned sequels to this book.

Jerry C. Harrison
Major General, U.S. Army
Deputy Chief of Staff
for Technology Planning
and Management

EXECUTIVE SUMMARY

The U.S. Army is pleased to inform Congress, the Defense community, and the general public of the accomplishments of Army contractors within the scope of the Small Business Innovation Research (SBIR) Program.

Through the Army's SBIR Program, small businesses have begun tearing down the technological and scientific barriers that had impeded progress in areas of concern to our nation's defense. The Army, in funding research and development efforts by small businesses, has been able to seize and retain the technological initiatives that are so vital in this era of change and challenge.

This Army Phase III Review focuses on twenty-one projects which the Army feels deserve special recognition. The contractors that performed this work have achieved significant innovations in fields such as membrane technology, artificial intelligence, radar, weather forecasting, and ultrasonic spectroscopy. Although these companies are small in size, they are characterized by the wide scope of their vision, capabilities, dedication, and talents that make outstanding achievements possible. Many of the contractors would have been unable to fund their research and development without benefit of the SBIR Program.

This *Army Phase III SBIR Review* is the first scorecard of Phase III results. The U.S. Army is proud of the accomplishments of all of its SBIR contractors. Unfortunately, it was impossible to include profiles of all the SBIR projects and contractors; such an undertaking would have required an inordinate amount of time and filled several volumes. The projects and companies profiled attest to the Army's belief, as so aptly phrased by former Secretary of Defense Caspar Weinberger, "We find it good business to do business with small business."

SBIR PROGRAM DESCRIPTION

The SBIR program is divided into three phases: Phase I, Phase II, and Phase III.

Phase I: Concept Feasibility

Twice a year, the Department of Defense publishes an SBIR Solicitation. This document describes the programs that are of interest to the Army as well as the other services and Defense agencies. Small businesses then submit proposals to the Army based on the criteria and guidelines contained in the SBIR Solicitation.

Phase I contracts are awarded for a study of the feasibility of the projects in the Army's areas of interest. The awards are for $50,000 over a six month period. Available funds permit support of approximately 20 percent of the proposals received.

Phase II: Research and Development

Firms that successfully complete a Phase I study are eligible to submit Phase II proposals in that area of study. The Phase II awards fund research, development, and prototype production. The awards cover a period of two years, and average $450,000. Due to funding constraints and the Program's desire to support only the most productive efforts, only about 40 percent of Phase I projects progress to Phase II.

Phase III: Production and Commercialization

Success in Phase II often leads to Phase III. The SBIR contractors normally obtain funding for the production and commercialization of their product or service from the private sector. The Government, through its agencies, also provides financial support for contractors whose products will be used by the U.S. Government. By law, no SBIR funds are extended for this phase.

SBIR PROGRAM BACKGROUND

SBIR PROGRAM GOALS

"What counts is not only how much we spend, but how well we spend it."

—Robert Samuelson

Since its inception in 1983, the U.S. Army's SBIR program has played an increasingly important role in the advancement of numerous technologies while effecting significant cost savings. In order to fully appreciate the achievements of the SBIR contractors profiled in this book, one must first understand the program's goals.

It is widely known that few businesses succeed in the long term without a business plan. A plan is essential in guiding the direction of the organization as it grows, confronts daily challenges, and plans for the future.

When an organization's viability depends on research and development, it is doubly important to define goals and expected results. Peter Drucker has observed, "Research has to be measured like everything else. For improvements, it is fairly easy to set specific goals and to measure them. In managed evolution, too, goals can be set. Innovation, however, requires appraisal. Spending money does not by itself guarantee results."

In these respects, the U.S. Army's SBIR Program is similar to a large business. The Program's orientation is research and development; it is effectively a large business working closely with small businesses.

Three recent events have greatly influenced the direction of the Army's SBIR Program. The first was a 1987 SBIR briefing, when Undersecretary of the Army James Ambrose broadened the notion of innovation and specifically focused

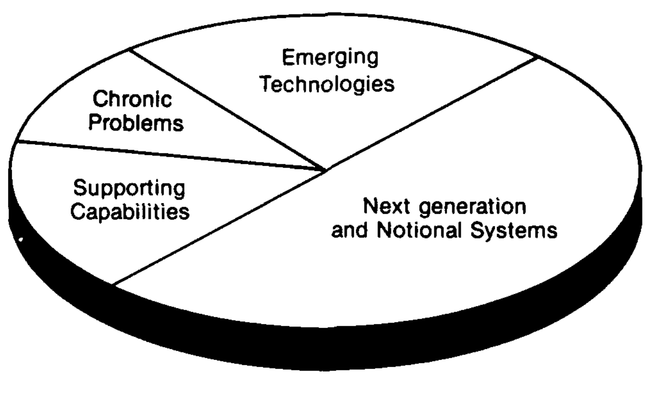


Figure 1
Technology Base Resource Distribution Objective by Descriptive Domain

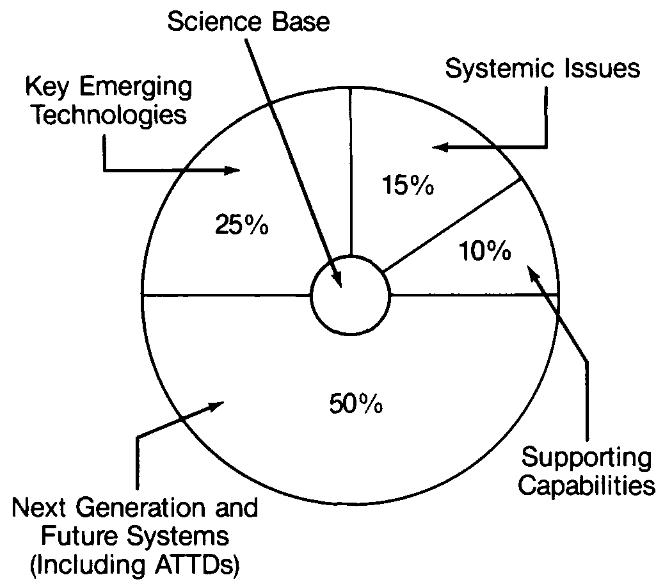


Figure 2
Investment Strategy

the thrust of the program on Phase III results. Numerous concerns were addressed at that time: What was the Army doing to insure that SBIR research and development initiatives were truly significant? How did the Army insure that successful Phase II projects were transitioned to Phase III? Who was championing these successful ventures? Who was keeping score? The briefing also addressed the issue of a reward system to recognize those successful laboratories or research, development and engineering (RDE) centers that had transferred SBIR Program technology into useful products.

In June 1988, the Army established a select panel to steer projects toward successful Phase III transitions. The first task of this panel is to select topics for the DOD SBIR solicitation on the basis of their anticipated benefits. The panel's primary focus has been to judge the anticipated benefits of each project prior to publication in the Department of Defense SBIR Solicitation. A strategy was developed with the Army laboratories and RDE centers to generate specialized solicitation topics linked to funded budget lines in the Five Year Development Plan (FYDP) to satisfy the goal of achieving Phase III transitions. The end user of the technology is identified in advance. For example, the FY 89-95 Instrumentation and Acquisition Plan was used by TECOM to alert their user community of new SBIR technology. This process continues in Phase II, when the panel again reviews each project for linkage to the Army's anticipated Phase III benefits. In 1990, the panel previewed over 700 new projects and selected 479 topics for publication.

The third major event was publication of the Army's Technology Base Master Plan (ATBMP), in April 1989. This plan emerged from the Technology Base Investment Strategy (See Figure 1). The ATBMP, now at the center of the Army's

SBIR initiatives, outlines the Army's strategic approach to investment in the technology required to satisfy future defense requirements. Hence, most of the projects described in this book can be matched with either a key emerging technology, a next generation/future system (including Advanced Technology Transition Demonstrations, or ATTDs), a supporting capability or a systemic issue (see Figure 2). Others represent the application of innovative solutions to key issues in producibility and the development cycle.

At present, there are 42 laboratories and RDE centers participating in the Army's SBIR program. These sponsoring locations also play a role in monitoring the potential results of SBIR projects. Each project is viewed from the Phase III perspective: Will the project's results influence military material quality or become part of the Army's defense system? This perspective has become the standard for assessment within the Army SBIR network. In a successful Phase II project, endorsements from the Army's Program Managers or Program Executive Officers are frequently the main commitment of the sponsoring laboratory or RDE center.

Through participation in the SBIR Program, small businesses have been drawn into this larger effort through cooperation with the Army's laboratories and RDE centers. These companies have been quick to learn of, and respond to, the Army's needs. Often the SBIR contractors' work leads to spin-off technologies that exceed the Army's initial requirements. These results further enhance the value of the Program.

National defense is the ultimate goal of the Army's SBIR Program. Through cooperation with small businesses, the Army has harnessed innovative technologies while realizing unexpected benefits in civilian applications, cost savings, and the work of people who exemplify the finest in American ingenuity.

Statistical Profile of SBIR Contractors

In November 1989, approximately 280 SBIR contractors received questionnaires concerning their participation in the SBIR program. The survey was taken to elicit information about the contractors as a whole, and to gather comments about the administration of the Army's SBIR program.

The responses to the survey yielded a valuable profile of the average SBIR contractor. Based on these companies' responses, we are able to report that:

- 59 percent of the companies have been in business less than 10 years;
- 49 percent of the companies are research oriented;
- 52 percent had less than $1,000,000 in revenue the previous year; and
- 58 percent of the contractors employ fewer than 20 people.

These figures indicate that the typical U.S. Army SBIR contractor is indeed a small business, as defined by revenue and staff size. Yet these contractors are not small in vision or capability, as the technical summaries in this book so eloquently attest.

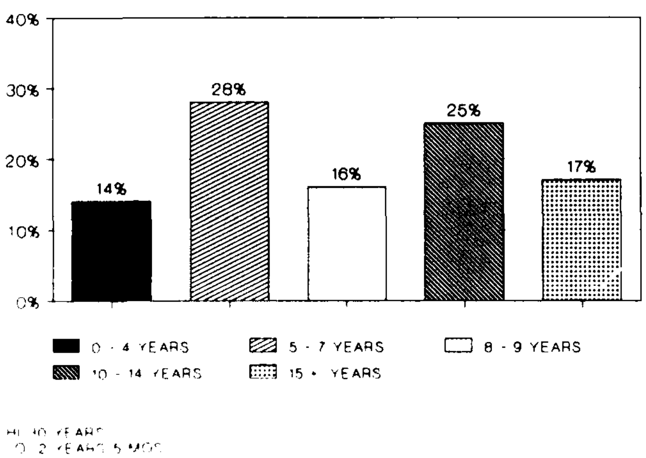
The following is an analysis of responses to key survey questions.

■ How long has your company been in business?

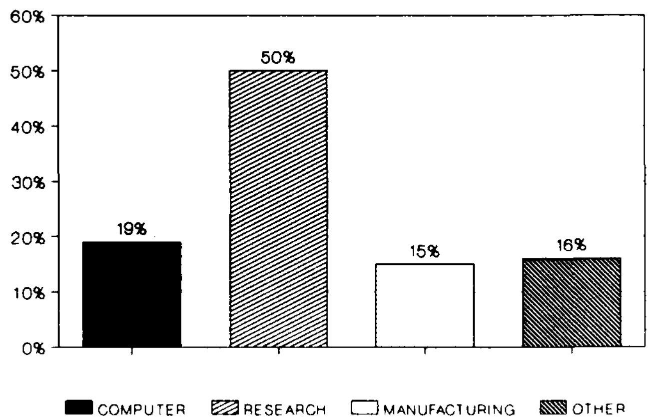
Less than 20 percent of the companies surveyed had been in business longer than 15 years. 29 percent of the companies had been in business between 5 and 7 years. Contractors' longevity in business ranged from 2½ years to 30 years.

■ What is the orientation of your company?

Nearly half of the businesses (49 percent) were devoted to research and development. Eighteen percent were computer firms; sixteen percent were manufacturing firms. The remaining seventeen percent were oriented toward consulting, biotechnology, education, or other pursuits.



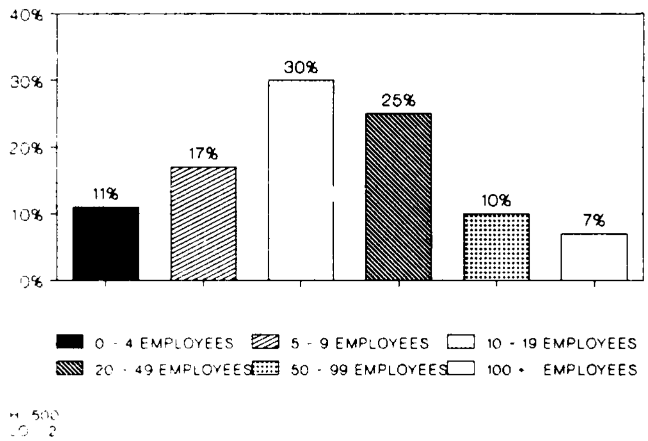
Years in Business



Nature of Business

■ How many people does your company currently employ?

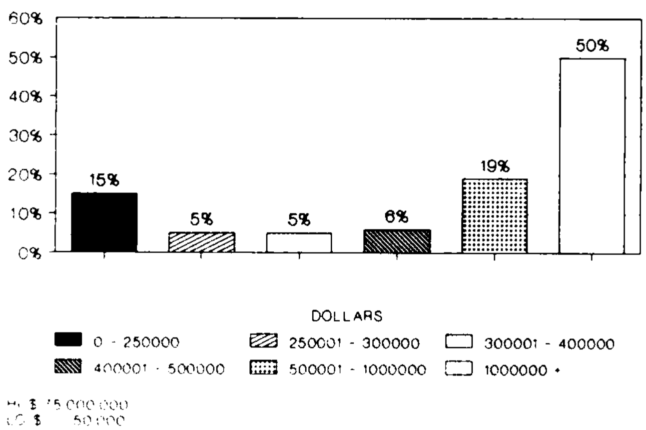
The contractors reported a large range in staff size. The smallest business had two employees; the largest, (maximum permissible under SBIR) 500. Thirty percent of the firms had between 10 and 20 employees, while 8 percent employed 100 people or more.



Number of Employees

■ What was your company's revenue last year?

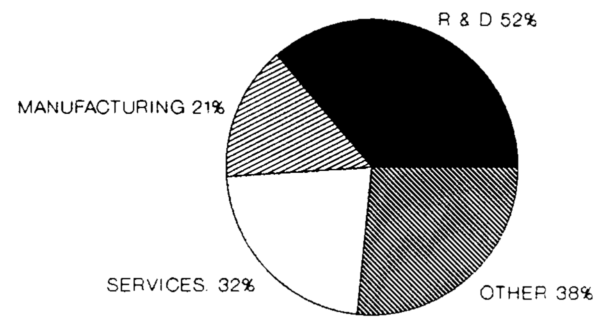
The annual revenue of the contractors varied tremendously, from $1,195 to $39,000,000. Twenty percent reported revenues between $500,000 and $1,000,000 for the preceding year, and forty eight percent had revenues in excess of $1,000,000.



Revenue Last Year

■ How were last year's revenues spent?

The varying responses to this question permitted only an approximation of how the SBIR contractors spent their revenues during the preceding year. The majority, roughly 52 percent, indicated that their funds were spent primarily on research and development. About 32 percent was spent on services; manufacturing, roughly 21 percent. The balance of the revenues was spent in other categories.



DOES NOT REFLECT 100% BECAUSE SOME COMPANIES SELECTED MORE THAN 1 CATEGORY

Areas Where Companies Spent Last Years Revenue

Computerized Vehicle Endurance Testing

Sophisticated mathematical analyses of signals and data have long been applied to a variety of mechanical and electrical engineering real-time problems. Unfortunately, the complexity of such tasks required the use of expensive, bulky, and power-hungry electronic devices, mostly built with bit-slice bipolar logic. Although Complementary Metal Oxide Semiconductor (CMOS) equivalents of bipolar devices have been in existence for some time, the new generation of CMOS microprocessors designed specifically for high-speed computations offers a very attractive alternative to bit-slice designs, especially for low and medium data rates (1-10 kHz).

The U.S. Army Combat Systems Test Activity (CSTA) at Aberdeen Proving Grounds has an ongoing program to support Vehicle Endurance Testing. The goal of this activity is to establish a correlation between mechanical performance, vehicle failures, and the vehicles' mechanical stress. In the process of vehicle testing, data are collected, processed, and recorded with a Vehicle Performance Recorder. This system, shown in Figure 1, is a ruggedized vehicle performance recorder based on the CMOS Industrial Microcomputer Bus (CIMBUS). However, field use of this recorder revealed a need for a peripheral that would perform floating point operations as well as high-level signal processing functions (FFT, filtering, etc.) in real time. Currently available devices fell short in one or more of these categories.

To meet these requirements, DVP Inc. designed an inexpensive, high-performance CMOS Array Processor (Figure 2). This device fits into one of the standard slots in the vehicle performance analyzer (VPA) or any CIMBUS-compatible backplane, and has the capability to communicate both on and off the bus. The array processor is an intelligent, CIMBUS-compatible peripheral that gets its data and commands from a master microcomputer over a common bus. The key point in development of this product dealt in the sophisticated high-level software routines optimized for the hardware environment. Through the use of these routines, the array processor performs integer and floating point

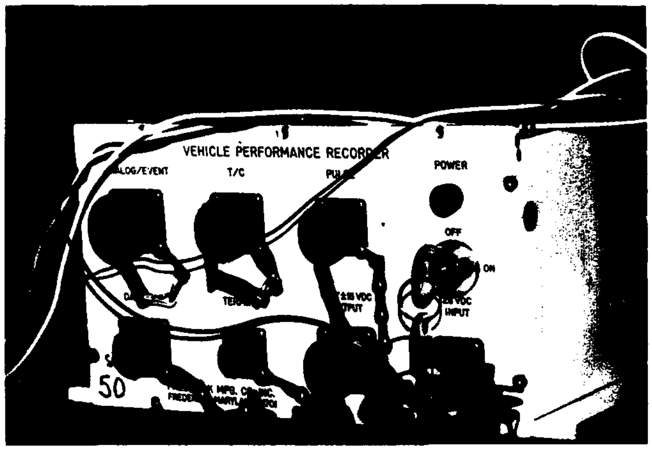


Figure 1
The Vehicle Performance Recorder

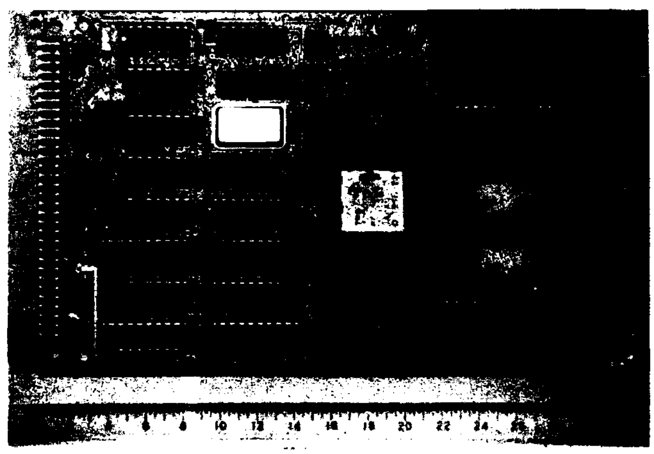


Figure 2
The Array Processor Hardware

arithmetic and transcendental functions and can support common signal processing functions such as fast fourier transform (FFT), convolution, correlation, filtering, and probability density function accumulation. A large amount of onboard data and program memory allows the board to store a significant number of programs and process long arrays of data without creating bottlenecks on the data bus. Its low power consumption and low cost are achieved through the use of off-the-shelf, all-CMOS circuitry. The high-level software routines afford a truly flexible digital signal processing (DSP) development environment without the need of knowing the details of the DSP assembly code, making this product extremely useful and relieving the end user of the necessity of knowing chip-specific command sets.

A distinctive feature of the array processor is its ability to handle expression evaluation. A user can specify a formula, enter data, and get a final result without intermediate operations and steps. This operational concept results in a significant reduction of interprocessor data exchange and frees the bus master and data bus for other operations.

The current development platform is a standard 80×86 microcomputer, which can serve as a host to download programs and data for product operation. In addition, once all software modules are complete, the same platform can be used to write pseudocode, where high-level command instructions can be used to create user-specific DSP code.

The array processor will be used for spectral analysis, statistical data processing, filtering, and matrix calculations. To ease software development, a high-level language support system (subset of the 'C' language programming environment) is being developed. The Army contracted to purchase over 100 boards, with several dozen more pending, prior to the completion of the Phase II effort. The expertise developed during this project has also led to a spin-off project with Frederick Manufacturing Company. The reason for this accelerated schedule is twofold: the potential for the product was demonstrated early through the timely completion of a hardware prototype; and preliminary performance analyses and a detailed software specification gave positive assurance of the product's ultimate disposition.

The commercialization aspects of this product, outside of the Army's applications, hinge on the successful completion of DVP's in-house development of a DSP precompiler. With these tools in place, modularized DSP code could be written without the need of having to know the specifics of the assembly language chip-specific command set. These routines, with the proper hardware interface, could be used for virtually any DSP application.

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Phase III Impact

- *Sold over 100 boards to the Army prior to completion of Phase II*
- *Spin-off project with Frederick Manufacturing Company*

Accurate Scale Model Units for Erosion Control

Man cannot stop the constant erosion by the sea, only slow it down. Since millions of dollars worth of buildings have been built along and on the ever-changing waterfronts, efforts must be made to safeguard property. Up until 40 or so years ago, quarried stone or round boulders were used for breakwaters. At that time, precast concrete units were developed and tested, and are now commonly used in breakwater construction where armor stone is not economically feasible or design conditions demand stone sizes larger than the quarry can yield. Breakwater designs normally consist of a quarry stone core covered with a larger stone filter layer. In all cases where precast units are used, it is necessary to lay down a layer of quarried or natural rock for a supporting foundation. The top layer, be it stone or precast concrete, is designed to dissipate the wave action. The top or armor unit is, at most, two layers thick.

EWS's Phase I task was to develop new cost-effective methods of making scale model armor units. These scale model units are used for testing purposes by the U.S. Army Corps of Engineers at their Waterways Experiment Station (WES) in Vicksburg, Mississippi. The station contains the largest collection of structures and facilities in the free world for the design, testing, and development of armor units, jetties, and breakwaters for beach and harbor protection. Corps of Engineers scientists have developed model tanks, wave flumes and wave generators to test ocean conditions on a scale model basis.

In casting the scale model armor units, the components are weighed into separate measuring cups or containers. Twenty five or more are weighed and set out at a time, then filled. Vacuum or pressure is then used to eliminate as much air as possible. Normally the setup or gel time is two to three minutes. Immedi-

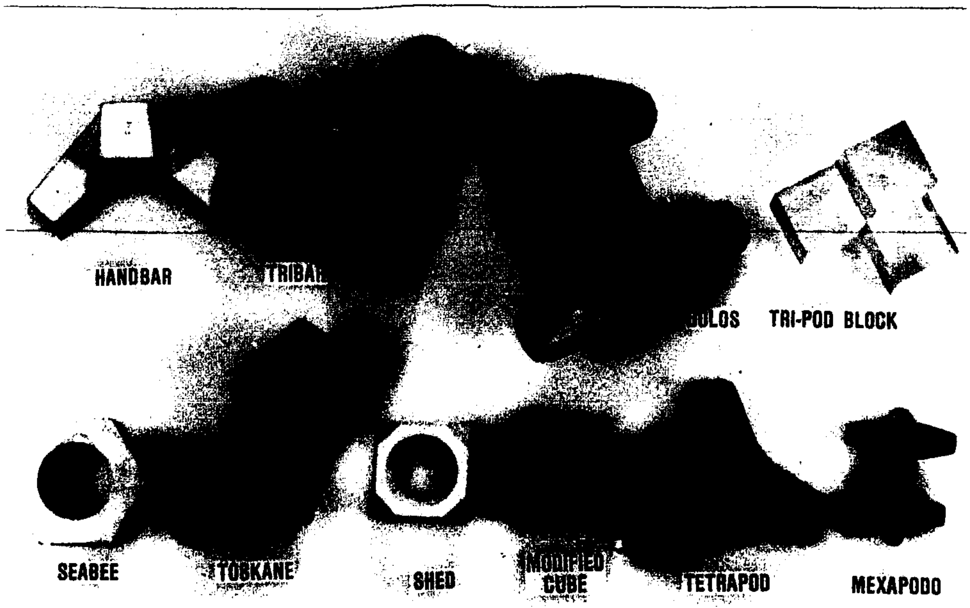

Figure 1
Scale Models of Armor Units Used in Erosion Control

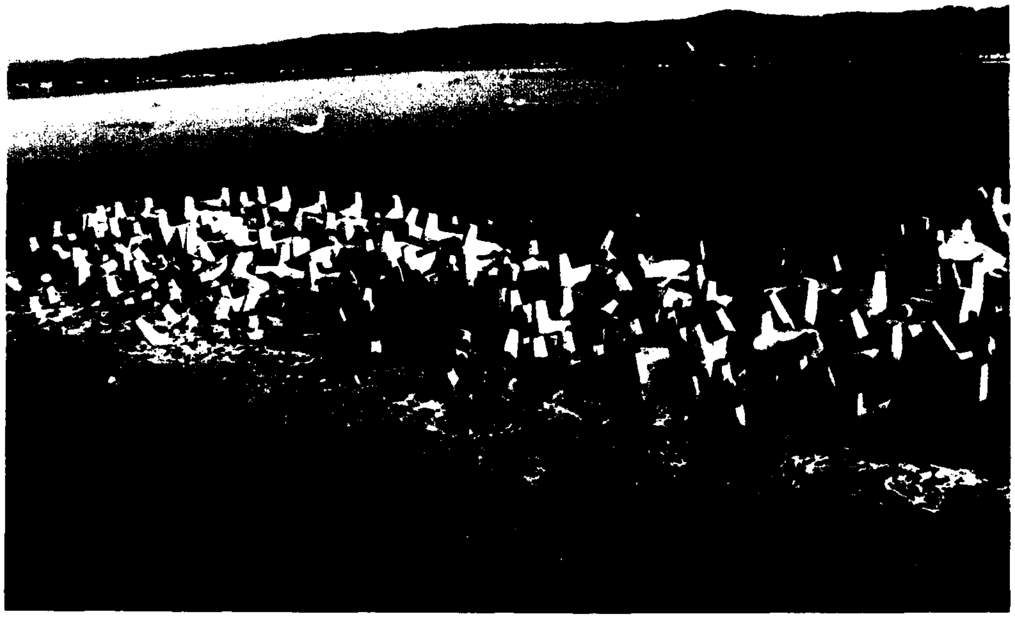

Figure 2
Dolos Units in Use in Crescent City, California

ately after gelling, the units are demolded and placed aside to cure.

After casting, each unit was given a number, usually with a permanent marker. Then it was weighed in air, marked with its weight and then weighed in water. The date of manufacture, mold number, weights and values were recorded. From this data the specific gravity, tolerance and acceptability were determined. We were also able to run various quality and production controls with this system. This is a time consuming procedure; however, EWS felt that it was necessary to insure that all units were within the tolerances. After the units were weighed, and before shipment, an additional sampling and random testing program was run. Samples were taken at random from the various production runs, usually at least 8 percent and sometimes more if the batches were under 30 pieces. These samples were checked for dimensional tolerance and given a break test. Then one-half of the sample batch was again checked for weight in air and water. When we shipped units, we were confident that they were within tolerance. Since we now have a permanent record of each unit, the weathering and performance can be checked at any time.

As a result of this work, EWS now makes the most accurate, cost-effective scale model armor units in the free world. EWS has successfully sold and rented these units to civilian testing facilities. The Corps of Engineers' WES Coastal Engineering Research Center is pleased with these results, and has recommended EWS to other division within WES as a suitable and potential source of materials. EWS has also tendered numerous quotes on supplying scale models for projects outside the scope of the SBIR project.

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Phase III Impact

- *EWS now makes the most cost-effective, accurate, scale model armor units in the free world*
- *Sales and rentals to civilian testing facilities*

Integrated Machine Intelligence for Robotic Systems

Integrated System's ongoing Phase II program aims to bring artificial intelligence methods into the realm of practical, commercially supported robotic control systems. Currently available commercial robotic systems provide very limited flexibility in automation because of difficulty in programming them to perform tasks in a dynamically changing environment. Advanced robotic systems in laboratories are programmed on expensive computation hardware using many separate development tools. The process is lengthy and prone to errors. The resulting robotic systems are too expensive and unreliable for use in operational systems or on the manufacturing shop floor.

Our system uses artificial intelligence techniques such as real-time expert systems, fuzzy logic, parallel adaptive control, and finite state machines in conjunction with conventional analytic robotic control strategies such as inverse kinematics, inverse dynamics, trajectory planning, and force/torque control. The system allows simulation, design, real-time implementation, testing, and verification of robotic real-time software covering all of the above mentioned aspects of machine intelligent control. Code generators automatically generate efficient real-time multiprocessor kernel and application code in C. The kernel enforces all the complex time dependencies and communications specified at simulation and design stages. The final product will also generate Ada code. The resulting code is efficient enough to allow implementation on commercially available, inexpensive processors.

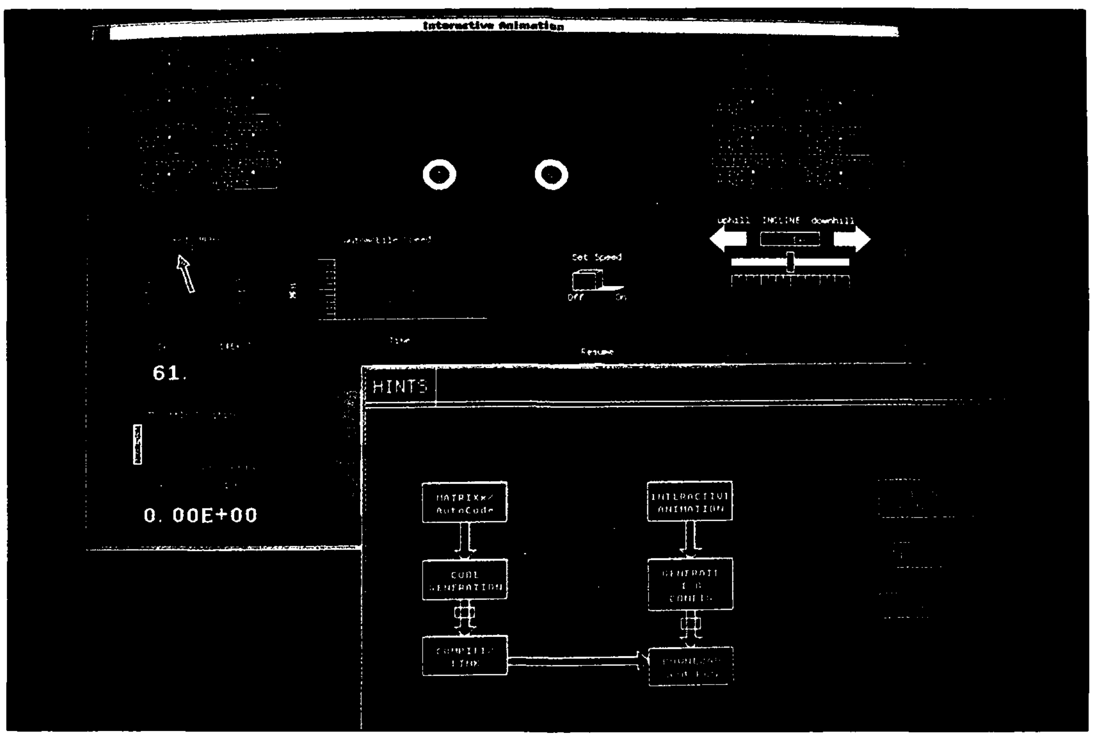

Figure 1
User Friendly Interface Permits Easier Design and Implementation of Real-time Intelligent Control

The resulting system has shown reduction of an order of magnitude in the time required for development and testing of a typical, complex, machine intelligent robotic function. The current real-time target computing hardware is about five times less expensive than similar robotic systems at other laboratories using commercially available artificial intelligence tools.

Integrated Systems is testing the system at an Army laboratory for ammunition handling and weapon loading functions. The system has two robotic arms and uses vision, speech, and force/torque sensors. The demonstration will show both reactive and deliberate responses to real-time sensory information. Successful demonstration of the system will lead to evaluation of the robotic technology in reducing tank and howitzer crew sizes. Other applications of the integrated real-time machine intelligence tools are automotive control, electric power plant control, self-repairing flight control, fault tolerant control of the space systems, and factory automation. We are actively pursuing applications in each of these areas. Integrated System's Matrix X/ER has been successfully commercialized and sold to a number of companies, including FMC.

Integrated Systems is the prime contractor under the Precision Aircraft Armament Control Experiment (PAACE) Program. Integrated Systems has successfully adapted and applied advanced control techniques to achieve sub mil dispersion for the air-to-air automatic cannon system. This technology is also being considered for application to the development of an ultra high performance gun stabilization system for the Block III tank.

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Phase III Impact

- *Army is testing system for use in ammunition handling and weapon loading*
- *The Matrix X/ER has been sold to a number of companies, including FMC*

A Hand-Held Composites Inspection Tool

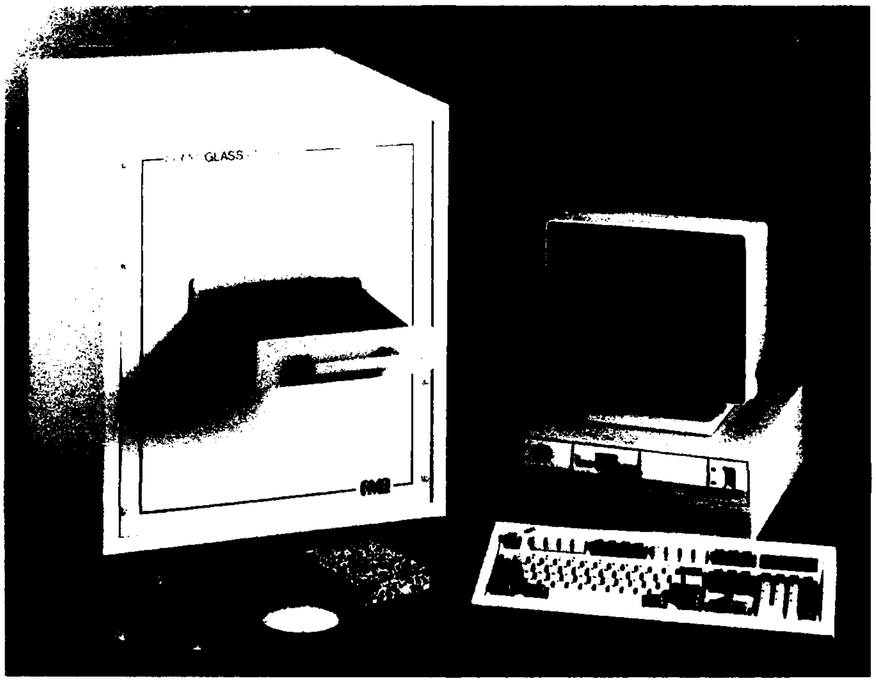

Figure 1
The Compuglass Analyzer

The use of composite materials in armor is a new technology which promises to reduce the weight and cost of armored vehicles while increasing the safety of the personnel inside the vehicle. As with any new technology, methods must be developed to ensure that the manufactured parts meet the required specifications.

The goal of the program is to build a hand-held inspection tool to verify that the correct number of fiberglass layers were used in the construction of the armor components. The instrument being developed under this contract will meet the quality control needs of the manufacturer as well as the incoming inspection needs of the Army.

Until the inception of this program, no rapid nondestructive test was available to accurately determine the number of layers of reinforcing fiber in thick armor composites. Conventional methods used by the plastics industry relied on either mechanical or chemical techniques. However, these methods for evaluation of glass and filler contents are destructive, labor-intensive, and time-consuming. A better solution to this problem is being developed using radiation backscatter techniques. This approach provides rapid, accurate, nondestructive instrumentation for measurements of fiber content in composites.

The instrument's working principle is based on radiation scattering by various co.ıstituents of the composite material. The sensing head uses a detector and a gamma ray source. The radiation source is small and well shielded so that the operator is not exposed to the radiation. In operation, samples with known fiber content are radiometrically interrogated by the unit and used to establish specific calibration curves. The calibration data are stored in computer files.

The goal has been met, and a lightweight, hand-held unit has been built and tested which can measure the number of layers in thick composite parts with an accuracy better than ± 1 layer. The instrument includes the software, computer interface, and electronic circuitry needed for a stand-alone system. This technology has numerous non-military applications. We have already developed, and are selling, industrial process control instruments based on the technology used in this instrument.

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Phase III Impact

- *Development of the first tool for nondestructive measurement of fiber content in composite materials.*
- *Sales of x-ray backscatter analyzers for process control in manufacture of TV tubes*

Advanced Techniques for Weather Forecasting

The wide dispersion of Army forces on the modern battlefield and the complexity of current electro-optical weapons systems have increased the need for forecasted weather parameters that could be used as input to Tactical Decision Aids (TDAs) that perform weather effects analysis. Since weather varies with time and locality, weather forecasting and effects analysis must be constantly reappraised to retain usefulness as combat intelligence. Consequently, research and development is ongoing to devise new ways of automating mesoscale weather parameter forecasting in the battlefield environment.

Consultant's Choice, Inc. (CCI) believes that weather parameter forecasting is one of the fundamental functional requirements for the Army's Integrated Meteorological System (IMETS), which will be used by the Air Force Staff Weather Officer (SWO) to support Division and Corps staffs who are primarily engaged in planning tactical operations. The incorporation of automated weather forecasting models in IMETS is therefore crucial to the Air Force SWO's ability to provide forecasts utilizing a diverse set of weather parameters that will be used as input to many TDAs. Automated weather forecast models are essential to tactical weather forecasting in the field and should be used just as the National Weather Service forecasters use the Limited Fine Mesh/Model Output Statistics (LFM/MOS) models.

Previously, CCI had investigated expert systems for creating tactical weather forecast models. In Phase I and II research, standard and non-standard neural net approaches were investigated. Through this effort, it was found that a proprietary algorithm, called Goal Oriented Pattern Detection (GOPAD), held the greatest potential to achieve Army objectives. GOPAD is technically described as a statistical, optimizing,

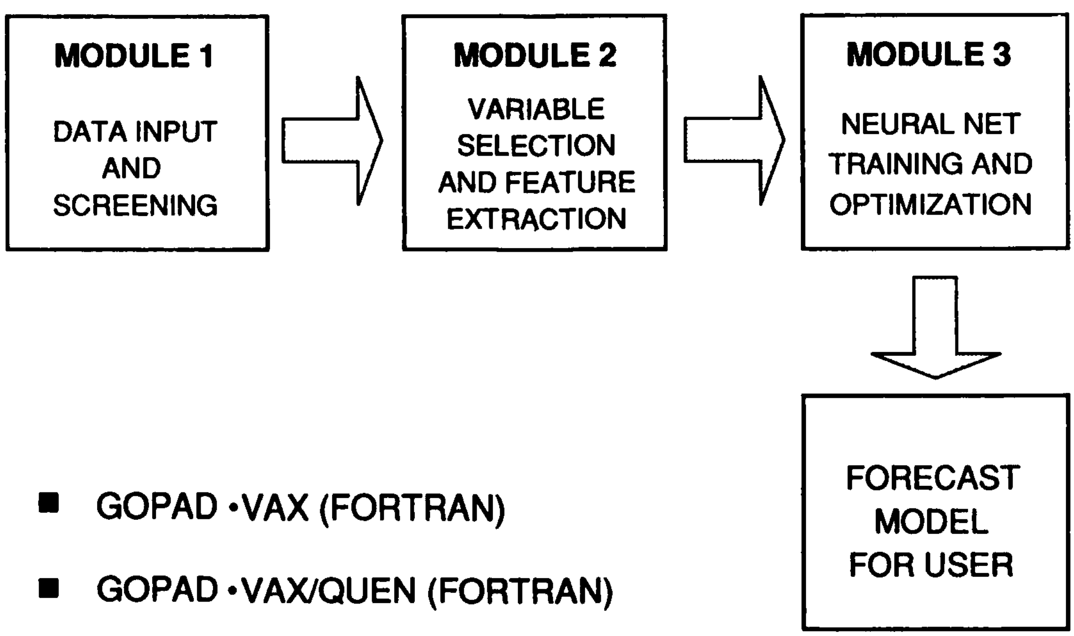

Figure 1
An Overview of GOPAD

machine-learning, analogue, forecast model creation software tool (Figure 1). GOPAD produces a tactical or mesoscale, real-time weather forecasting software program that executes in seconds on any computer and in any language. CCI found the forecasting skill of two GOPAD models to be very high, in spite of the limited data that were used.

During CCI's research, GOPAD was used to produce two experimental models, GOPAD-Atlanta-RIR and GOPAD-Shootout-89. The GOPAD-Atlanta-RIR was a Probability of Precipitation (PoP) model developed for Hartsfield International Airport in Atlanta, Georgia. Using minimal information, this model produced forecasts with skill scores that were above those of the National Weather Service forecasters, with some qualifications. The GOPAD-Shootout-89 model was a severe and significant weather forecast model that was independently tested by NOAA during a real-time severe and significant weather forecasting exercise called Shootout-89 that took place in the Boulder and Denver, Colorado areas. A quantitative and qualitative performance evaluation report of all six models that participated will be published in the Fall of 1990.

In general, the GOPAD model development tool creates optimal machine-derived indices from highly correlated variables, identifies the optimal statistical relationships between all candidate predictor variables and indices using a very large historical weather data set, and automatically produces a non-linear forecast model. This model development process is also able to reveal the underlying physical relationships upon which the model is based in the form of exemplars, thus enabling a meteorologist to examine a model's forecast. The GOPAD development software tool can be used to automate the creation of a wide variety of very accurate tactical forecast models such as fog as it is related to visibility and ceiling; precipitation amounts and type; severe weather such as tornadoes, hail, lightning, and wind gusts; and cloud distribution, types, and coverage.

The GOPAD technology offers great potential for producing a wide variety of mesoscale forecast models that should routinely match or exceed the day-to-day performance of the National Weather Service forecast models with some qualifications. The Army has purchased CCI's weather forecasting models for use on a tactical Army computer system. Since there are very few forecasting models available to help the Air Force SWO who supports Army Division or Corps staffs in the field, GOPAD represents a very important technology that can quickly produce forecast models for any potential combat area. Commercially, GOPAD could be used to develop unique, region specific forecast models for activities that depend upon weather information. Furthermore, the GOPAD algorithm is being implemented on a super minicomputer with the assistance of a major corporation. CCI is negotiating a new research effort with a major utilities holding company to investigate the potential of a GOPAD model to improve the accuracy of the temperature forecasts in specific regions. If an increase in forecasting accuracy is possible, then it could result in very large energy savings by more efficient distribution of electrical power across a multi-state power grid.

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Phase III Impact

- *Army has purchased weather forecasting models for use on tactical computer system*
- *Major corporation has provided assistance in implementing GOPAD algorithm on super minicomputer*

Advanced Electronic Control Unit

Under the SBIR Program, Vista Controls Corporation has developed a high performance Reduced Instruction Set Computer (RISC)-based servo controller. This system, the Advanced Electronic Control Unit (AECU), is the first known application of a RISC microprocessor used as a robotic controller. The AECU product has shown such promise that it has been selected by General Dynamics for the M1A2 Tank Program, and has also been selected by several commercial companies for other digital controller applications. An SBIR expenditure of less than $0.6M has turned into a multimillion dollar cost savings to the Government. Our story is the classical SBIR success story of a small business advancing the current state of the art, with the resulting technology transfer yielding tremendous cost savings.

The M109 self-propelled 155mm howitzer (Figure 1) is an integral part of the U.S. Army's arsenal of conventional weapons. As a long range tactical weapon, the 155mm howitzer's role in our national defense will continue to grow in importance. However, new technology poses a significant threat to this proven artillery piece. The potential enemy has fielded computerized radar round-tracking and return fire capability. This means that to survive deployment on the 21st century battlefield, the howitzer must be able to fire multiple rounds, then quickly disengage and relocate within 60 seconds of firing the first round. Currently the M109 howitzer cannot meet that performance level. The two critical areas needing improvement are reduction in labor intensive functions and improvement of overall howitzer speed, survivability, and performance.

In an earlier attempt to meet these goals, the Armaments Research Development Engineering Center (ARDEC) designed and built a robotic howitzer testbed using off-the-shelf technology. That vehicle, the Robotic Howitzer Demonstrator (RHD) testbed, has proven the feasibility of planning on a fully automated howitzer for the future. However, several technological obstacles hindered ARDEC engineers from meeting all their goals.

The primary obstacle to attaining the RHD goals

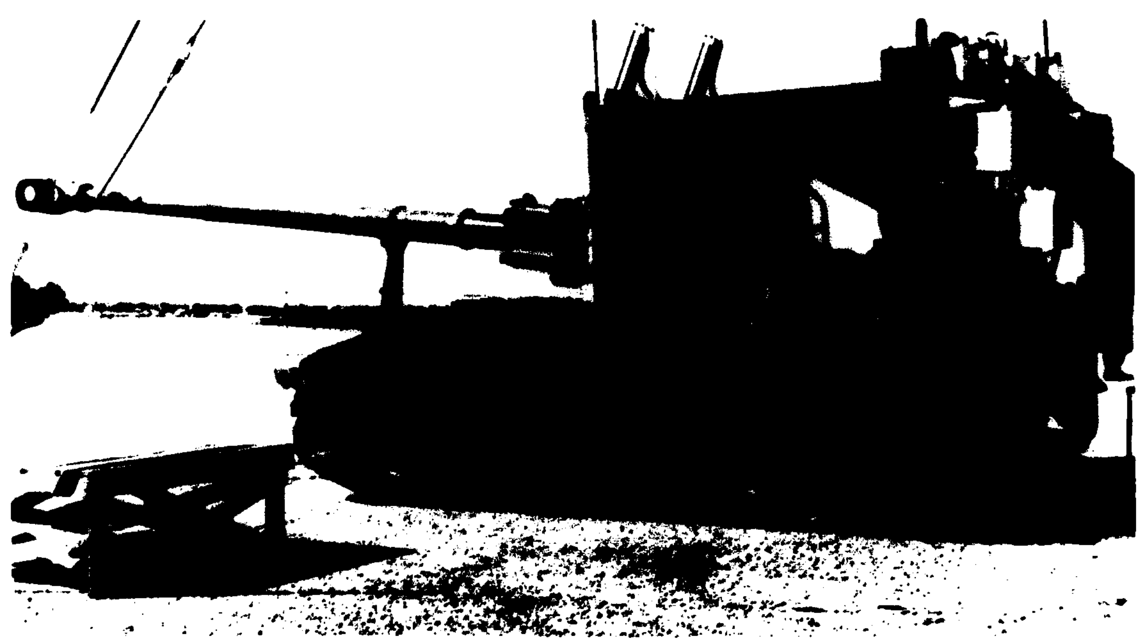

Figure 1
The Army ARDEC RHD Vehicle with Modified M109 155mm Howitzer

was the lack of a suitable digital controller. To address that specific requirement, the Fire Support Armaments Center at ARDEC awarded Phase I and II SBIR contracts to Vista Controls. Those contracts provided for development of an AECU to allow the original ARDEC-designed RHD to perform as well as intended. The RHD demonstrator was chosen as the appropriate showcase for the AECU.

The first challenge was to find a fast enough microprocessor: complex motion calculations had to be repeatedly processed anywhere from 500 to 2000 times per second. A thorough study was conducted of the available microprocessors. The clear winner was a new RISC microprocessor just recently released. The chip was fully supported with an arithmetic co-processor and software development tools, and was about to be fully militarized.

Secondly, the microprocessor had to have an operating system with very low overhead so that context switching could occur in real time. Various operating systems (OS) were evaluated, but none of the available systems could support the application. A real time OS was written to provide foreground/background task switching, priority task assignment, real time clock interrupts, and synchronized intra-task data communication. The result is a stripped down, very efficient multitasking OS.

Third, robotic systems are always designed to control real world hardware. Therefore, the processor must have a fast, low overhead path to its associated input/output (I/O) devices, and accommodate many different types of I/O. A closely coupled I/O bus was added to the AECU system. This allows a single controller to be used with many different I/O modules, and the same controller may be used for different applications.

The final concern was full system militarization. The AECU was designed from the start as a military product. This high speed controller system met strict specifications in component quality and reliability, manufacturing process standards, environmental and shock testing, and Ada compatibility. In addition, every part used is also available in a commercial version. An experimental system can be quickly prototyped using less expensive commercial parts, and a militarized version can then be produced and fielded with no redesign necessary. This feature of inexpensive prototyping and quick-turnaround militarized production was key to the product's first sale (M1A2 program).

The actual AECU system delivered to ARDEC consists of a computer installed in a MIL-qualified rack enclosure and power supply. The computer itself has multiple high speed processor boards on a trade name backplane, each processor having its own dedicated attached I/O module. After refurbishing the testbed vehicle and retrofit of the AECU system to the existing robot, the upgraded RHD system met a number of important objectives. The robot will accept and handle existing M109 self-propelled howitzer 155mm ammunition. It has the capability to automatically select and load powder and prefuzed projectiles. The robot loader will support automatic down/uploading of charges and projectiles off/onto the vehicle. Both electrical and hydraulic actuators in the testbed vehicle are under programmable digital servo control. All technology developed may be easily retrofitted into the existing NATO supply of fielded 155mm howitzers. Design does not prohibit manual backup in case of failure.

Development will continue as both ARDEC and other contractors build towards the requirements of the future field artillery system. A complete artillery autoloading capability is considered crucial to the desired howitzer of the future. The AECU developed during this SBIR project is an ideal candidate to meet these more advanced robotic goals.

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Phase III Impact

- *Used by Tank Automotive Command before sales to ARDEC*
- *ACEU selected by General Dynamics for the M1A2 Tank Program*
- *Commercial use of ACEU in digital controller applications*

An Automated Target Recognition System

Figure 1
Sample Image of Passive Automatic Infrared Sensor Technology (PAIRSTECH) Test Set

This SBIR Phase II contract is funding a prototype Automatic Target Recognition (ATR) system for ground-to-ground armor fire control applications. The system uses a Forward Looking Infra-Red (FLIR) U.S. common module sensor and unique algorithms developed by Susquehanna Resources and Environment (SR&E) under prior SBIR Phase I contracts. A viable path for technology transfer to a "fieldable" integrated and embedded decision support system is being maintained, and multisensor fusion is a planned product improvement. Although developed for FLIR data, the generic nature of the image processing technology allows it to be easily adapted to virtually all types of digital image data.

To date, the Government has funded several other image-based ATR efforts for ground combat vehicles. These systems are dependent upon pixel level intensity thresholding and/or the first order statistics of a moving window. As a result, their capabilities are severely limited. The systems are prone to false alarms, and are incapable of even the most rudimentary classification of observed targets into categories as broad as tracked vs. non-tracked vehicles. In short, an operational image data based ATR system for ground-to-ground applications has yet to be delivered.

SR&E Inc. has developed advanced digital image processing technology that represents a significant departure from the conventional methodologies of ATR and computer vision research. The development consists of a set of intelligent region-growing segmentation algorithms that operate under the assumption that targets have complex image structures. This process first partitions the entire image into spatial units of homogeneity using dynamic algorithms that evaluate edges, surfaces, size, shape, and various statistical measurements of intensity and texture. The most distinctive feature of this method is that it generates a relational data base of the image. Within the image's data base, image features (or regions) are represented as objects, with each object possessing specific attributes such as size, tone, measures of texture, location, and various descriptions of shape.

Once the system has created a relational data base of the image data, the objects are operated upon by an image interpretation knowledge-based system or "Image Expert." The Image Expert system has no intrinsic difference from other knowledge-based systems. The data base employs a model-based heuristic analysis to identify contiguous objects that, as a unit, exhibit the spatial characteristics of a target. This includes positional variables such as near, adjacent, right, left, above, below, etc. The comparative advantage of this methodology over pixel-based signal processors is that it allows a target to be defined by the spatial connectivity of its component parts. In FLIR imagery (as with other sensors), a target is typically composed of several distinct areal units, each having very dissimilar tonal and textural characteristics. It is the differences in the spatial arrangement of these distinct components that allow targets to be discriminated from one another, and the system to have a low false alarm rate. Once a possible target is identified, its contour is then defined as the outer limit of the union of such sets of objects. This method greatly improves the quality of extracted target contours (silhouettes), allowing the use of shape descriptors in target classification and identification, and yielding a even higher level of confidence. Figure 1 shows a sample image from the Passive Automatic Infrared Sensor Technology (PAIRSTECH) characterization test set.

The current system's performance indicates that the objectives of this contract will be met, if not exceeded, by the contract completion date, July of 1990. The potential applications of this unique method of image processing are not limited to ground-to-ground FLIR targeting tasks. The design of the system's algorithms is not based on sensor-specific signal characteristics; they are generic processors controlled by a rules table and sensor-dependent target models. The image partitioning rules table and the model-based heuristics in the Image Expert may be easily changed for differing sensors and objectives. This capability results in dramatic reductions in development cost and lead time, and is especially valuable in multi-sensor fusion tasks. Short term testing has already demonstrated that the system is effective with Synthetic Aperture Radar (SAR), Laser Range Data (LADAR), Visible and Near-Infrared Video (TV), and Multi-Spectral Satellite (MSS) imagery. Potential commercial applications of the system include robotic/machine vision, medical imaging, mechanical parts inspection, and environmental monitoring.

In addition to this current SBIR contract, the Center For Night Vision and Electro-Optics (CNVEO) has awarded SR&E a contract under which the system is to be installed at CNVEO for testing and evaluation. The developed ATR concept has been tested for advanced cruise missiles application within an SBIR project sponsored by the Naval Surface Warfare Center (NSWC). SR&E is under contract to General Dynamics/Convair Division to provide ATR capabilities to its CVIS development effort. In addition, SR&E is under contract to System Planning Corporation to perform ATR tasks with SAR data in support of the J-STARS program.

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Phase III Impact

- *Contract with General Dynamics to provide ATR capabilities to CVIS*
- *Contract with CNVEO for system installation, testing, and evaluation*
- *Contract with System Planning Corporation to use ATR in support of J-STARS*

Recovery of Drinking Water from Vehicle Exhaust

The objective of this program was to develop an onboard system for recovering potable water from the exhaust stream of military vehicles. Development of such a system would address one of the most formidable problems facing modern fighting forces: ensuring that troops have adequate supplies of water. Tanks, personnel carriers, and the other vehicles used by today's highly mobile Army cannot carry sufficient water to sustain troop operation for long periods of time. A practical method is needed to produce safe water supplies in the field—ideally, as close to the point of consumption as possible, since the weight and volume of water make it difficult to transport.

An onboard water generation system based on recovering water from the exhaust of military vehicles offers a promising means to solve this critical troop supply problem. About 2 liters of water vapor is produced for each kilogram of diesel fuel consumed, so it is theoretically possible to support troops based on the fuel consumption of heavy military vehicles. However, over the last 25 years attempts to recover this water vapor from exhaust streams using condensation processes have failed: the water produced was dirty, foul-smelling, and not suitable for use by troops.

The membrane-based onboard water generation system developed by Bend Research, Inc. for the U.S. Army Tank-Automotive Command solves problems associated with earlier attempts at water generation. The process, which is shown in Figure 1, is based on a synthetic membrane configured in a compact, hollow-fiber

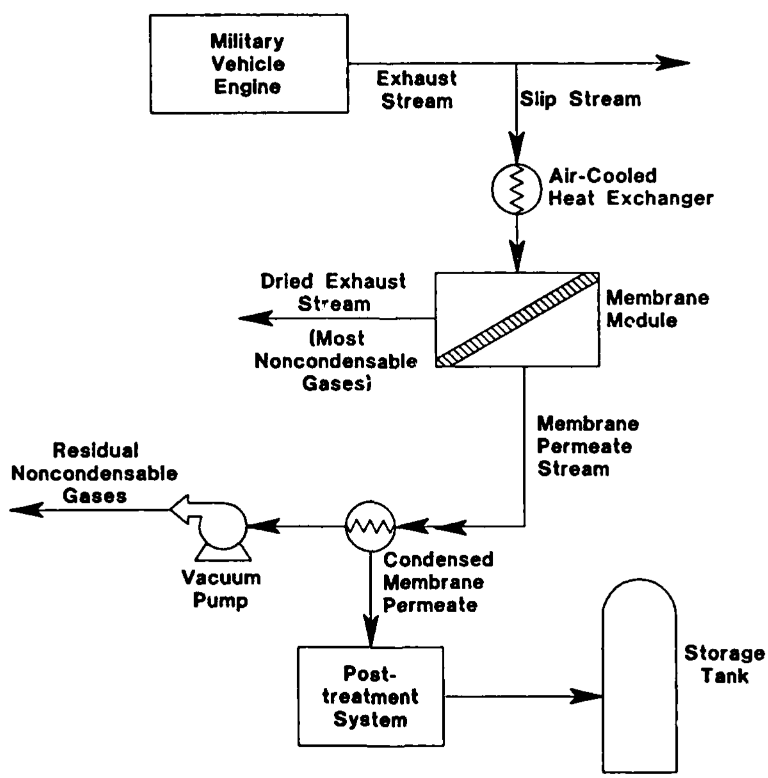

Figure 1
Schematic of the Bend Research Onboard Water-Generation System

membrane module. A slip stream is taken from the humid exhaust stream of a military vehicle and fed into the module, where it contacts the hollow-fiber membrane. The hollow-fiber membrane is permeable to water vapor, but relatively impermeable to the other components of the exhaust stream. A vacuum selectively draws the water vapor through the membrane, leaving most noncondensable gases and all particulate components in the dried exhaust stream. The water vapor is compressed, condensed, and stored in a tank on the vehicle.

During Phase II of this program, we focused our work on three objectives: design and development of a high-performance membrane module for use in the system; design and development of a supporting mechanical system; and design, construction, and field testing of a preprototype water-generation system. We successfully accomplished all three Phase II objectives, designing a compact preprototype system that was successfully field tested on a High-Mobility Multi-Wheeled Vehicle (HMMWV).

Figure 2 is a photograph of the Bend Research preprototype onboard water generation system. The preprototype system was installed behind the driver's seat on a HMMWV supplied by the Oregon National Guard and was powered by the HMMWV's electrical system. A series of seven runs of the preprototype system was conducted by Bend Research and Army personnel from April 17 to April 21, 1989. During a typical run, the system was operated for about 1 hour while the HMMWV was driven on a 64-kilometer course. The route allowed us to test the operation of the preprototype system over a range of "loads" on the HMMWV diesel engine. The test successfully demonstrated that water can be recovered from the exhaust of a HMMWV under realistic operating conditions using the preprototype water-generation system. Specifically, we learned that at least 0.5 L/hr of water can be recovered using 3.4 square meters of hollow-fiber membrane; that the membrane modules and supporting mechanical system can withstand the vibration and high temperatures (130 °C) expected during actual field operation; and that the supporting mechanical system can be made compact and can operate on the power supplied by the electrical system of the HMMWV.

The water recovered by the system is clear and odor-free, but must undergo a post-treatment "polishing" step before it meets standards for potable water. How-

Figure 2
Bend's Preprototype Water-Generation System

ever, because most of the contaminants in the exhaust stream do not permeate the membrane, the post-treatment required is much simpler—and the required equipment much less cumbersome—than that required for earlier water-generation systems investigated by the Army.

Work on this SBIR program produced a practical preprototype onboard water-generation system for military use. Based on our success in this program, the Army approved a Phase III funding commitment for optimization of the system. In addition, work on this program led to a breakthrough in membrane technology: development of a new type of hollow-fiber membrane suitable for a wide range of dehumidification and dehydration applications. The technology developed in this program led to more than $1 million in additional R&D contracts from Government and private clients, in part because of the national media attention this program focused on our firm. Development of a commercial product line based on the technology developed in this program is near completion, and discussions are in progress with several firms interested in products based on this new technology.

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Phase III Impact

- *Over $1 million in additional R&D contracts from Government and private customers*
- *Development of commercial product line*

High Resolution Ultrasonic Spectroscopy System for Nondestructive Evaluation

With increased demand for higher resolution ultrasonic evaluation, computer based systems or work stations become essential. In this project, the ultrasonic spectroscopy method of nondestructive evaluation (NDE) has been employed to develop a high resolution ultrasonic inspection system supported by modern signal processing and pattern recognition methods. The basic system comprises a PC (IBM AT compatible with 386 processor), a Pulser/Receiver, and a Digital Oscilloscope (Figure 1). The system is further supported by several customized software packages for remote control of the devices, signal acquisition and presentation, one-dimensional and multi-dimensional signal processing, pattern recognition, and B-scan image reconstruction. An optional neural network classification is also provided. With this system, we are now able to investigate the characteristics of hidden flaws in great detail. Signals may be processed on-line once acquired or stored on disk for later retrieval for off-line analysis. For these signals, we can build up a trained data-base (TDB) for automated classification of defect types.

The hardware components are commercially available. Although the system itself is still under development, the software package has been sold to a number of companies. A user-friendly and highly Interactive Ultrasonic Nondestructive Evaluation, Version 2.0 software package, (IUNDE), has been developed for use in the system. The following is a brief description of the functions provided by this package.

(a) Signal Acquisition
1. Acquire signal from a disk file (in ASCII format)
2. Acquire signal from STR *825 board
3. Acquire signal from LeCroy 9400 digital scope via GPIB

(b) Signal Processing
1. Power/Magnitude Spectrum by FFT
2. Power/Magnitude Spectrum by Burg's Technique
3. Power/Magnitude Spectrum by Chirp-Z transform
4. Correlation and Correlation Spectrum
5. Bi-correlation and Bi-spectrum
6. Deconvolution by Wiener filtering
7. Deconvolution by spectral extrapolation
8. Deconvolution by Least Mean Square Error (LMSE) Estimation
9. Hilbert transformation
10. Analytic Signal
11. Wavelet Transformation
12. Power Cepstrum
13. Miscellaneous—mean removal, moving average, circular shift, zero-padding, amplitude normalization

(c) Graphic Display
1. Display 1-D signals
2. Display 2-D signals in 3-D surface plots
3. Display 2-D signals in 2-D contour plots
4. Display multiple signals on one screen

(d) Feature Extraction and automated Defect Classification Options are provided to extract certain features from time and frequency domains. Automated defect classification is done by using the Nestor Development System NDS-1000 based on these features.

(e) Pattern Recognition
1. K-mean clustering
2. Nearest-neighbor classification
3. Bayes classification
4. Foley-Sammon transformation
5. Multiple Fisher's Discriminant
6. Nonlinear mapping

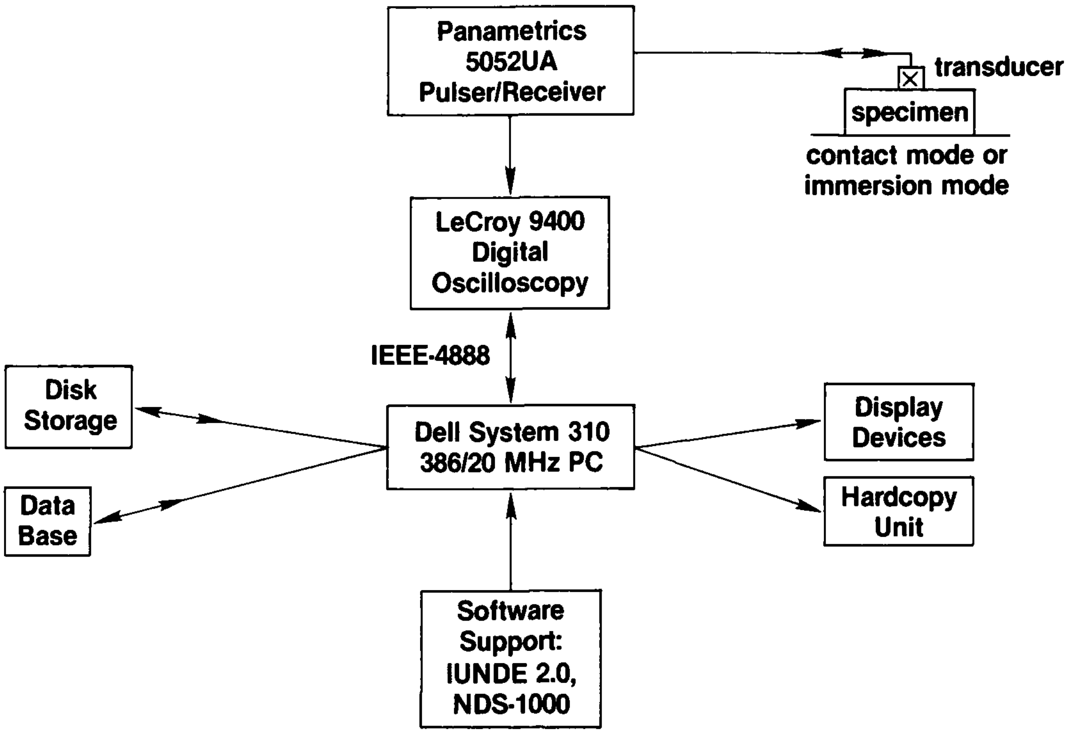

Figure 1
A Block Diagram of the High Resolution Ultrasonic Spectroscopy System

The ultrasonic spectroscopy-based high resolution NDE system can perform many complex nondestructive evaluation tasks to meet the inspection needs of the Army, other Government agencies, and the commercial sector. The software package is commercially available. Two companies, Karta Technology and Innovative Sciences, have incorporated the software into their systems. However, the system itself has not been completed.

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Phase III Impact

- *Software sold to a number of corporations prior to contract completion*

Millimeter Wave Instrumentation Radar

Often times, a single munition under test evaluation involves tracking and collecting data on that munition. With more modern munitions such as the Multiple Launched Rocket System, multiple payloads, or submunitions, are dispensed along with pieces of hardware. The presence of multiple targets creates a great deal of confusion in target selection. Under these circumstances, the risks are high that assigning the test range's data recording assets, needed to evaluate the munitions' performance, will be applied to a target of little interest.

The principal interest in evaluating multiple payload dispensing munitions is their terminal targeting performance. This phase of the test occurs in areas where fixed sensor systems can not adequately observe this portion of the flight path. Mobile systems are needed to allow the optimum positioning of these sensors for a given test, and to also permit the use of these same sensors

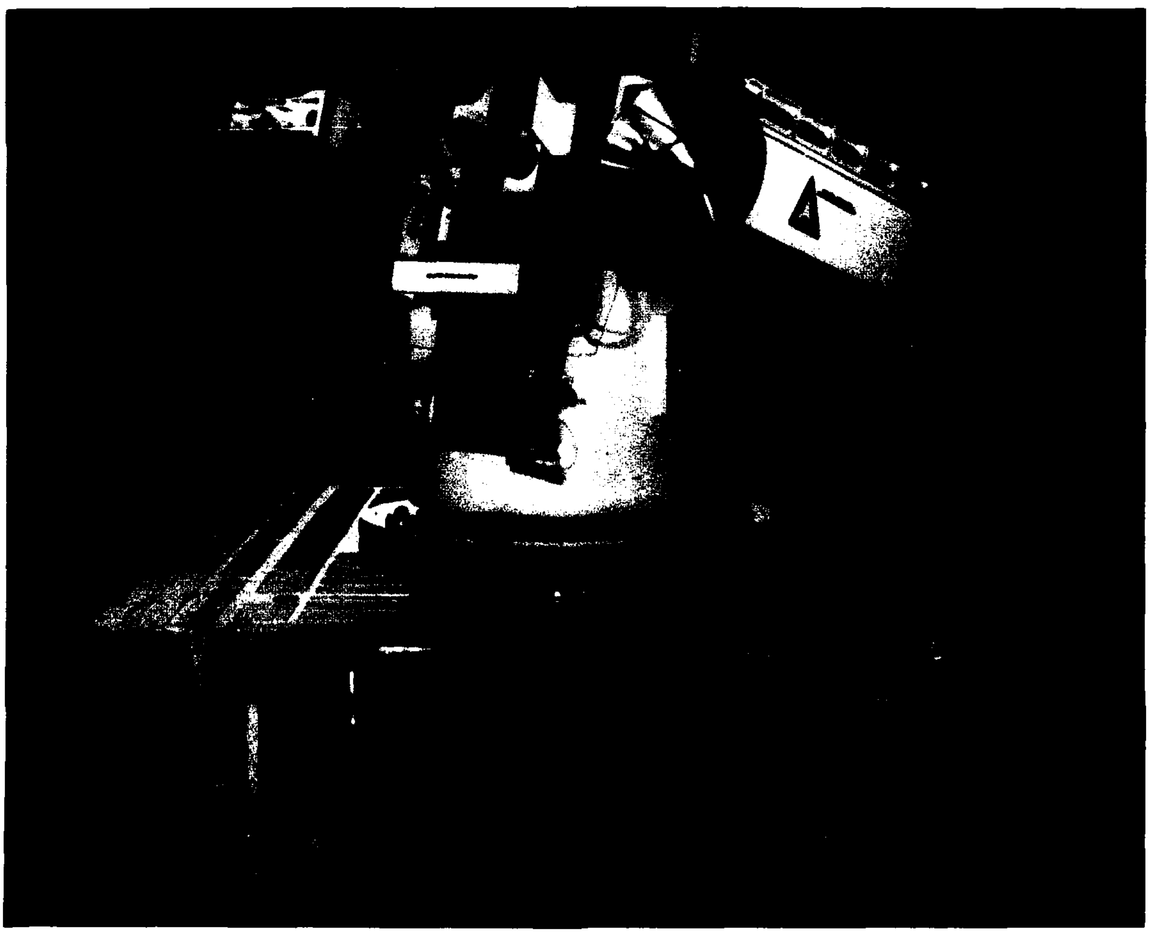

Figure 1
The Millimeter Wave Instrumentation Radar

Frequency	34.665 to 35.415 in 30 MHz steps	**On Mount Weight**	150 lbs
Antenna	24, 36 or 48 inch diameter 1, 0.66, and 0.5 degree beamwidths	**Controller/Processor**	Standard 19-inch rack, 18-inch high
Tracking Operation (36 inch antenna)	20 Km for a 0.1 sq. meter target 40 Km for a 3.0 sq. meter target	**Real-Time Output Data**	Choice of SDLC, HDLC, Ethernet, etc.
Transmitter	Solid state coherent design	**Power**	110/220 V, 50/60 Hz
Receiver	Fully coherent for high resolution Doppler	**Options**	• 250 and 1000 MHz bandwidth waveforms for resolving individual target scatterers • Real-time target selection • Increased recording duration • Target motion resolution work station • High speed fiber optic line over long distances for data recording and operator controls • Variations in package form factor
Clutter Suppression	40 dB through Doppler processing		
Data Recording	12 minutes minimum for digitized receiver samples and metric data. 90 minutes for metric data		

Table 1
Millimeter Wave 4D Instrumentation Radar Specifications

at different locations to observe a variety of trajectories. The need for mobility translates into small sizes for sensors. In fact, it is highly desirable to use existing transportable platforms and to add a new sensor to provide target selection.

Therefore, a new instrument must be capable of real-time target selection and be small enough to fit on existing mounts such as the widely available transportable kineto tracking mount.

Atlantic Aerospace has developed both the real-time algorithm needed to perform the critical function of target selection and an all solid-state radar, compatible with transportable tracking mounts, to provide the required Doppler data. The innovations include the development of a real-time target selection algorithm, solid-state coherent 35 GHz amplifier, and a radar architecture employing powerful high speed signal processors.

The Phase III effort to build a fully operational, field-deployable radar system had a strong foundation of technical assurance based on the Phase II results. The radar will be a fully functioning instrument which tracks in range, Doppler, azimuth and elevation. At this point, Atlantic Aerospace is in the final phases of system integration and about to embark on field testing of the entire system, including the mount.

The Millimeter Wave Instrumentation Radar is designed to operate on a kineto tracking mount, thereby offering a high degree of mobility for flexible test range support. It is intended to answer the need for affordable instrumentation radars and provide real-time target selection, accurate single-station metric data for trajectory reconstruction, and high resolution Doppler data for postmission assessment of aerodynamic performance through target motion resolution processing. The versatility of the instrument allows it to be used as a stand-alone instrument or as a complement to optical instruments sharing the same mount. In its optics complementary role, the radar can provide early acquisition and real-time target selection for handover to optical trackers. The design features an all solid-state approach, full coherency, extensive built-in tests, and is adaptable for higher signal bandwidths such as 250 MHz and 1000 MHz bandwidths that are useful for resolving individual target scatterers. Table 1 lists the important performance specifications for the Millimeter Wave Instrumentation Radar. Figure 1 shows the completed radar system on a kineto tracking mount.

The results of this research have provided the Army with an instrument which will be invaluable for evaluating the performance of modern munitions. Critical feedback will be provided to the munitions contractor, the procuring agency, and the command responsible for munitions deployment and operational support. These kind of weapons can be better evaluated and therefore enter the inventory with a firm knowledge of their performance.

The Millimeter Wave Instrumentation Radar will confidently permit White Sands Missile Range to collect data on the targets of interest for multiple target situations, thereby providing maximum effectiveness in characterizing modern munitions for a given number of firings. It is likely that the benefits of this research will be applicable to other service branches' test ranges for the evaluation of weapon systems of similar difficulty to evaluate. In fact, the Air Force has contracted for a second radar to be built and delivered to Hill Air Force Base in Utah. Other likely benefactors of this research are foreign test ranges such as countries associated with NATO.

An additional result of this research was the creation of another product which we have identified as the Model 1088 Range Tracker. This product is also designed to share optical mounts to provide range only data. The angles from the optical systems, plus the range from the Model 1088 system, will provide single station solutions for time-space position information.

The three phase SBIR approach will result in a successful product which will satisfy a specific need for munitions testing. The high risk nature of the research was well suited to performing a feasibility study first, a proof of concept effort second, and a useful product third. The case of the Millimeter Wave Instrumentation Radar is an example of research that will end in a successful conclusion. Atlantic Aerospace expects to deliver the product by October, 1990.

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Phase III Impact

- *Air Force contract for radar unit to be delivered to Hill Air Force Base, Utah*
- *Spin off technology resulted in development of Model 1088 Range Tracker*

Diamondlike Carbon Coatings for Optical Systems

Diamondlike carbon (DLC) coatings were developed to solve various problems associated with erosion in optical systems of airborne vehicles (rain, insects) and tactical ground vehicles (sand), as well as the problems associated with optical systems operating in salt water spray and chemically corrosive environments.

Diamondlike carbon (DLC) is an amorphous form of carbon that has a significant amount of Sp^3 diamondlike bonding and contains 20 to 70 percent hydrogen in the film. DLC possesses unusual and highly desirable properties such as extreme hardness, resistance to chemical attack, and transparency in the infrared region of the spectrum. These properties make DLC suitable as an abrasion and corrosion resistant, antireflective coating for the most broadband infrared optical materials. DLC does not bond easily to all substances, and special bonding techniques were needed. The objectives of this program were to compare the properties of DLC film produced by different techniques; to optimize the deposition parameters of these techniques for depositing DLC film on silicon, heavy metal fluoride, lexan, fused silica, zinc sulfide, BK-7 and KG-3 glass; to determine the effects of exposure to acids, solvents, extreme temperatures, humidity, radiation, and impact damage on the DLC film; to determine the effects of deposition parameters on film properties; to determine the fundamental chemical and physical properties of DLC film; and to assemble, test, and deliver to the Army a spectroscopic ellipsometer capable of determining optical properties and physical characteristics of these films or similar films.

DLC films were prepared as shown in Figure 1. The ion beam was produced by a plasma discharge of premixed methane and hydrogen gases. Extensive characterization of the DLC film was carried out using techniques such as Rutherford backscattering, proton recoil analysis, transmission electron microscopy, visible and infrared transmission and absorption spectroscopy, and ellipsometry.

The absorption of DLC was measured as a function of wavelength using a ultraviolet-visible dual beam spectrometer. The data were then used to calculate the optical band gap (Figure 2). Figure 3 shows the index of refraction vs. wavelength for unimplanted and fluorine implanted ion beam deposited DLC films.

The environmental resistance of DLC film was extensively tested. The films were found to adhere well on all of the substances. The film protected these substances from organic solvents of tricholoethane, acetone, methanol, and mineral acids of sulfuric acid, nitric acid, hydrochloric acid and hydrofluoric acid. The DLC coating's adhesion was not affected by exposure to the high temperature and high humidity environment of boil-

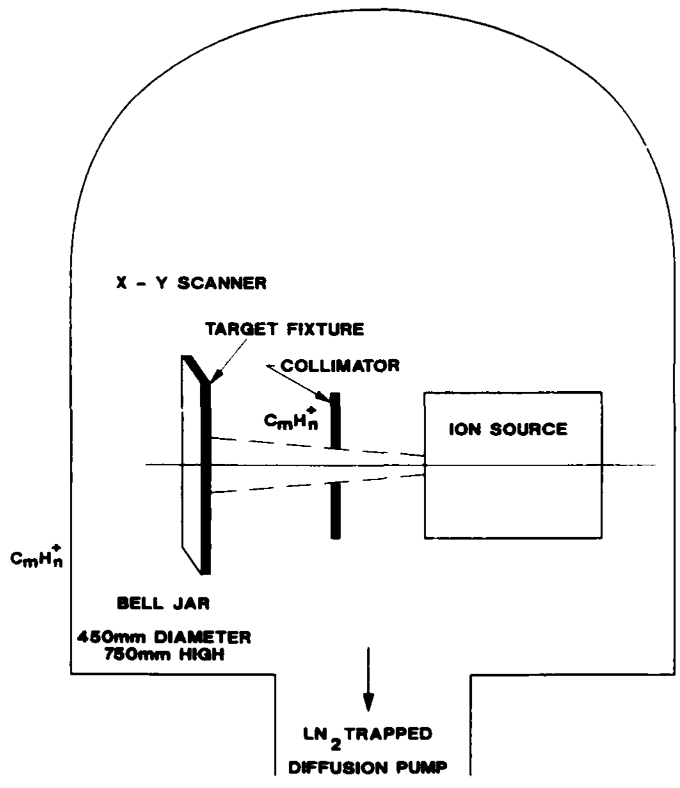

Figure 1
Ion-Beam Apparatus for Depositing Diamondlike Carbon Film

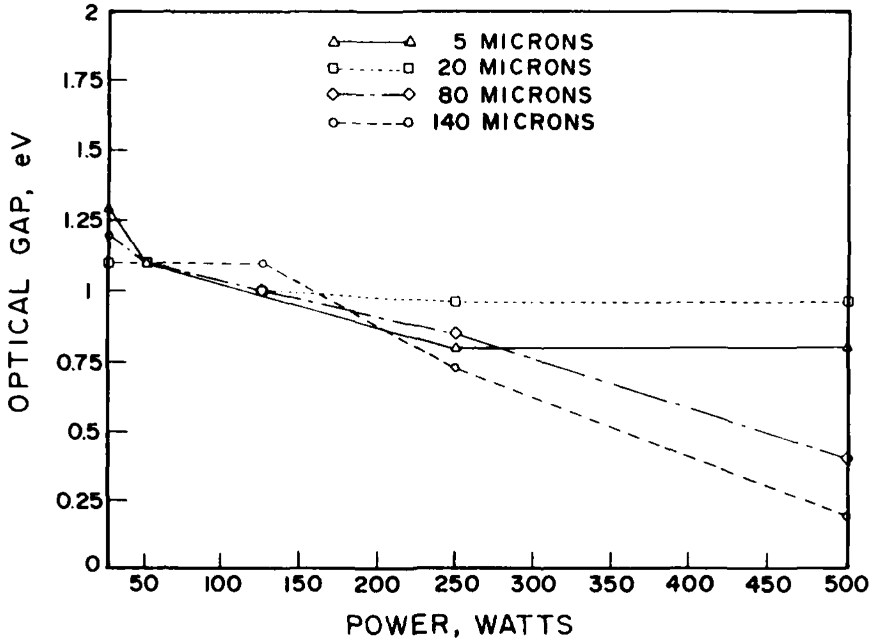

Figure 2
Optical Gap for Configuration II (13.56 MHz) Diamondlike Carbon Film

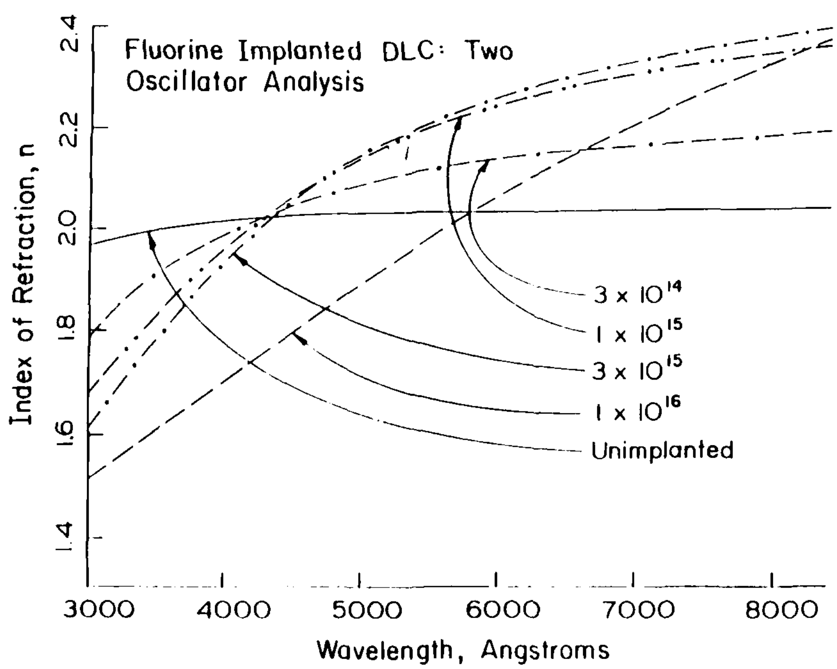

Figure 3
Index of Refraction for Ion Beam Deposited Samples after F Implantation at the Fluences Indicated

ing water for three hours, and the coating also survived the extreme temperature cycling of immersion in liquid nitrogen for two hours, warming to room temperature, and being heated to 98 °C for two hours. No loss of hydrogen content was observed after heating DLC films to 400 °C under vacuum.

In this program, DLC film was successfully deposited directly onto the various materials. The DLC film was found to be homogeneous, high density, amorphous, and pinhole free. The unique features of these coating processes are: (1) low temperature deposition, (2) DLC film adhered well on the optical substrate without coating the interface layers, (3) DLC film can be uniformly deposited to large areas, (4) superior chemical resistance against organic solvents and mineral acids, (5) excellent protection from high energy ion irradiation, and (6) DLC film adhered to all the substances under the extreme temperature cycling and moisture penetration. The deposited DLC film is thus suitable for abrasion and corrosion resistance and antireflection for the optical materials.

Work is currently underway at Universal Energy Systems, Inc. to scale-up the process to coat much larger, curved samples in its efforts to further transfer this technology to the field. The product is now commercially available, and has been sold to a number of companies including Martin Marietta, Tosoh of Japan, CVD/Morton Thiokol, and BioRad.

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Phase III Impact

- *Sales to numerous major corporations, including international clients*

Novel PC-Based Expert System Interfaces

Expert systems are programs which provide semi-intelligent support and services over a spectrum of applications ranging from intelligence to logistics to construction project management. In most cases, important data for the expert system must reside in databases external to the expert system program, and is often accessed by other applications, some written in the database programming language or a general-purpose programming language. Consequently, an interface is necessary to allow the expert system to access the data, to add new data, and to update or delete existing data, as in Figure 1.

While in principle expert systems can be developed in most general-purpose programming languages, experience has shown the task is carried out much more easily and efficiently in languages such as Prolog and LISP which are specifically oriented towards artificial intelligence programming.

On larger computer systems such as work stations, minis or mainframes, most database management systems (DBMSs) provide low-level interface libraries for some general-purpose programming languages. These can be (laboriously) used to construct indirect interfaces between Prolog or LISP and a database. On personal computers (PCs), the most widely used DBMSs either provide no external interfaces at all, or only a low level library for low level, general purpose programming languages.

PCs are ubiquitous throughout the Army and many other organizations. Thus there are many opportunities, even demands, to apply expert systems in the PC environment. However, the lack of adequate database interface tools has severely hampered the use of expert systems technology in the wide PC arena.

This project aimed to overcome this stumbling block by providing interfaces between Prolog and three of the most widely used PC DBMSs: dBase, R:Base, and BTRIEVE. Moreover, the project set out to provide much more powerful tools for building interfaces than are typically provided in any setting.

Briefly, the project developed a collection of expert systems (generically called the ALS DBI—Database Interface Toolkit) which nearly automatically write the complete code implementing an interface between a Prolog program and a particular database. There is an ALS DBI for each general DBMS (e.g., dBase). This DBI expert system understands the structure of databases managed by the DBMS, and also understands the needs of Prolog programs. The developer tells the DBI the name of the target database (and in certain primitive cases, the names of index files), and the DBI reads the information it needs from the database files or data dictionary. The developer also tells the DBI just how the Prolog program needs to view the data. The DBI then writes the code implementing the interface and stores it in a file. Subsequently, the developer simply loads this code together with the Prolog expert systems program being constructed, and the expert systems program has complete access to the database. Figure 2 illustrates this process.

Two versions of this expert interface building program, the ALS Database Interface Toolkit, have recently

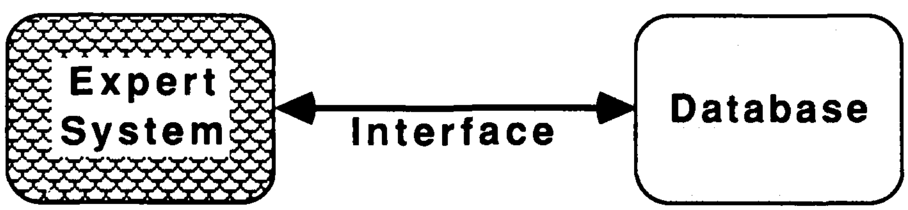

Figure 1
Interface between an Expert System and a Database

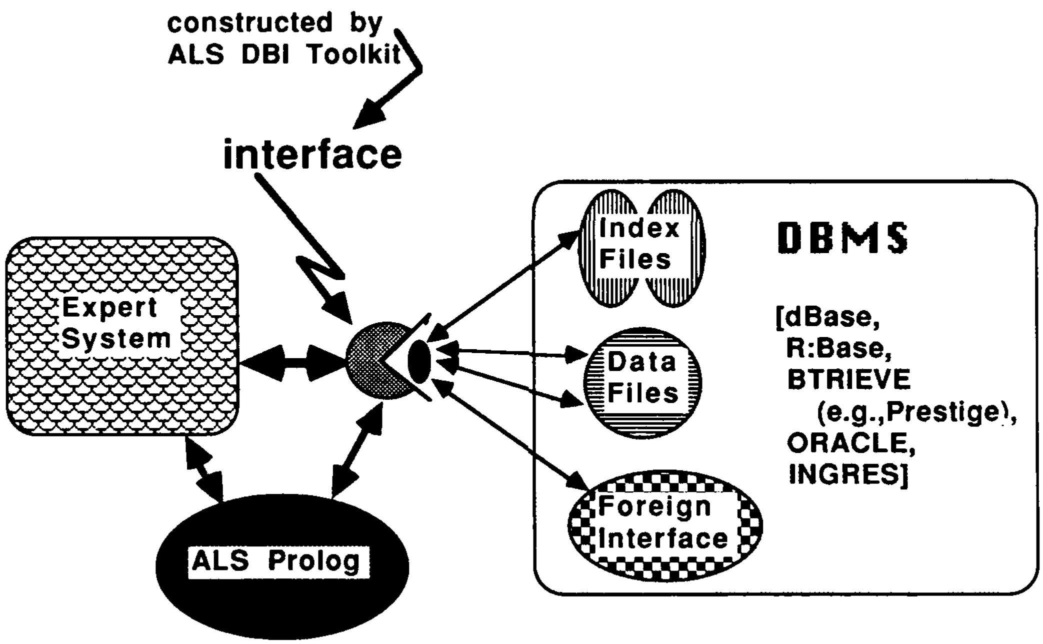

Figure 2
Construction of an Expert System/Database Interface

been introduced to the commercial market by Applied Logic Systems, Inc. The interface tools have been used in the development of a program improving the speed and capabilities of Army tactical intelligence processing. The interface tools were the basis of two successful SBIR proposals, to the National Cancer Institute and the U.S. Navy, and also are the basis of several current SBIR proposals, including one to the Army.

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Phase III Impact

- *Product is commercially available*
- *Interface tools used in Army tactical intelligence processing*
- *Additional successful SBIR proposals*

An Army Tactical Weather Hygrometer

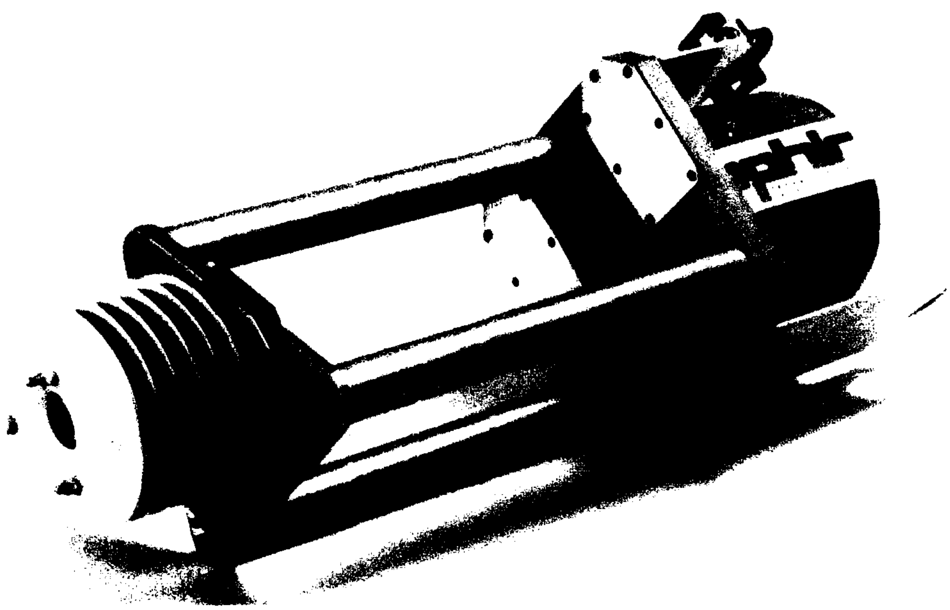

Figure 1
The IR-2000 Tactical Weather Hygrometer

Ophir Corporation's project involved the design, fabrication, and field testing of a hygrometer which is capable of providing accurate and reliable measurements of atmospheric humidity under battlefield conditions. Knowledge of the current atmospheric humidity is an important part of the Army's requirements for tactical weather information.

Measurements of humidity have traditionally been dependent on sensors that are not well suited to use under battlefield conditions. Some units depend on easily broken, wet- and dry-bulb glass thermometers, and require long periods of whirling to reach stable readings. Humidity sensors may be subject to changes in calibration due to direct contact of the sensing element with an atmosphere that frequently contains corrosive pollution. Chilled-mirror hygrometers work well under laboratory conditions, but give ambiguous readings in sub-freezing temperatures. The development of an infrared optical hygrometer provides the Army with a rugged instrument that can be operated successfully under battlefield conditions, free of the restraints imposed by other humidity measuring instruments.

The project progressed through phases involving theoretical studies, experimental work in the laboratory, design studies, and testing. The theoretical studies focused on providing sound bases for making decisions about design options. Since the transmission of infrared radiation is pressure dependent, it was necessary to derive a pressure correction solution that would permit use of the instrument over the full range of atmospheric pressure conditions anticipated in Army tactical operations. This solution was accomplished by a combination of theoretical modeling studies and experimental laboratory work.

It was also necessary to ensure that the infrared absorption bands characteristic of exhaust gas products such as carbon dioxide, nitrous oxide, carbon monoxide, methane, and the absorption bands of oxygen would not overlap the dual wavelengths chosen for operation of the instrument.

The basic sensitivity of infrared hygrometers was studied theoretically, using signal-to-noise ratio data derived from experiments and test of a Phase II prototype hygrometer.

The design studies addressed choices of measurement techniques, infrared detectors, optical path configurations, choppers, sample volumes, focusing optics, infrared filters, window materials, light sources, signal processors, auxiliary measurements such as pressure and temperature, data reduction techniques, and power and environmental specifications.

The Army Tactical Weather Hygrometer (ATWH), shown in Figure 1, was subjected to exhaustive testing in the laboratory and in the field. Tests covered signal-to-noise ratio, linearity, cross talk, path obscuration, transient response, sun interference, temperature coefficient determination, and humidity calibration. Before the hygrometer was delivered to the Army, it was carefully calibrated in the laboratory. Following the laboratory calibration, the hygrometer was subjected to five days of field testing in Colorado to verify the calibration. Following these tests, the instrument was shipped to White Sands Missile Range where further field tests were conducted. Those tests compared the performance of the ATWH to that of four other continuously recording humidity sensors. Of the five hygrometers tested, the ATWH was judged most accurate.

Acceptance of the ATWH by the Army has been gratifying. Their appraisal of the instrument can be best judged by their order for two additional hygrometers. The ATWH has been produced in a commercial version, designated as Model IR-2000. This model offers a power choice of 110 VAC or 28 VDC, rather than the 32 VDC specified by the Army. Firm orders for 18 IR-2000 hygrometers have been received. The purchasers include other Government laboratories and universities at home and abroad. Parts have been purchased for a second production run of 12 additional hygrometers. The overall success of the project can be judged from the sales already made and the fact that the U.S. Patent and Trademark Office has assigned Patent Number 4,874,572 to the invention.

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Phase III Impact

- *Product has been sold to Government laboratories, universities, and international customers*
- *Hygrometer has been granted a U.S. patent*

Improved Moisture Resistant Potting Materials/Techniques for Image Intensifiers

Exposure to high humidity in field use causes drastically shortened life in image intensifiers. This project involved the development and qualification of hydrophobic coatings and potting compounds with improved resistance to low level current leakage under very high voltage stresses (6000 volts over a gap of less than .180"). Other difficulties with current technology to be overcome are filling the very small gaps inherent in units before viscosity increases to the point where air removal by vacuum is impossible. Also, current materials are filled and the filler settles and must be carefully remixed to maintain uniformity. This filler also causes abrasion to the dispensing equipment.

The following chemical families were selected for evaluation in the development of hydrophobic coatings; silane, fluorosilane, vinyl silane, titanate, and zirconate (Tables 1 & 2). For potting compounds the chemical families of fluorosilicone, silicone, and urethane were investigated. The best results were found with fluoro/vinyl silane hydrophobic coatings and silicone potting compounds.

Insulation testing of the best hydrophobic coating, when used with the current silicone, show an improvement of 250× the insulation resistance with no hydrophobic coating. The insulation resistance with the best silicone potting formulation showed an improvement of 8× over current potting technology. Preliminary testing was conducted with one of the units submerged for 117 hours under water. At the end of the test, the unit was operated while under water. Image Intensifiers have been potted with the new hydrophobic coating and potting material and are now nearing the end of successful military qualification.

The materials developed under this program offer

Coating Number	Coating Type	Resistance in Ω
None	None	$0.1 \times 10^{12}\ \Omega$
NV1	Fluoro silane	$1.0 \times 10^{12}\ \Omega$
NV2	Vinyl fluoro silane	$1.5 \times 10^{12}\ \Omega$
NV3	Vinyl silane	$5.0 \times 10^{12}\ \Omega$
NV4	Hydrocarbon silane	$.005 \times 10^{12}\ \Omega$
NV5.1	Vinyl silane	$4.0 \times 10^{12}\ \Omega$
NV6	Amine silane	$.0005 \times 10^{12}\ \Omega$
NV7	Hydrocarbon silane	$.5 \times 10^{12}\ \Omega$
NV8	Titanate	$.05 \times 10^{12}\ \Omega$
NV9	Neoalkoxy zirconate	$.01 \times 10^{12}\ \Omega$
NV10	Vinyl fluoro silane	$25.0 \times 10^{12}\ \Omega$
NV10.1	Vinyl fluoro silane	$4.0 \times 10^{12}\ \Omega$
NV11	Vinyl fluoro silane	$1.0 \times 10^{12}\ \Omega$

Table 1
Suitability of Chemicals for Use in Hydrophobic Coatings

several unique advantages over existing technology, including the hydrophobic nature of the coating, very high insulation resistance of both the coating and of the base resin due to very high purity of the material, as well as molecular design, very low viscosity combined with long pot life for complete impregnation, and quick cure at elevated temperatures for production economics.

Sales have been made to several military contractors which produce Night Vision devices. Koford Engineering has also recently been notified that we have successfully completed military qualification. These materials will soon be commercialized for Night Vision image intensifier applications.

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Phase III Impact

- *Sales to several military contractors*
- *Commercialization anticipated in near future*

Compound	Type	Resistance Ω	Viscosity CP
NVP1	Filler free silicone	1×10^{12}	1,000
NVP1.1	Filler free silicone	8×10^{12}	1,000
NVP3	Fluoro filled silicone	1.2×10^{12}	3,700
NVP4	Filler free silicone	20×10^{12}	900
NVP5	Treated filler silicone	35×10^{12}	700
NVP6	Treated filler silicone	22×10^{12}	2,200
NVP7	Treated filler silicone	20×10^{12}	1,400
GE-615	Commercial filled silicone	3.5×10^{12}	3,500
DC-170	Commercial filled silicone	4.0×10^{12}	2,500
CONAP EN12	Commercial urethane	3.0×10^{12}	7,500

Table 2
Suitability of Chemicals for Use in Potting Compounds

Electronic Counter-Counter Measures for Communications Systems

Under the SBIR program, Prediction Systems, Inc. (PSI) has developed specific models and simulations to support analysis, design, test, and evaluation of Army communication systems. These models are computer-based representations of various equipment (both friendly and threat), the Army's users, and the electromagnetic environment in which they operate. These models, which are "products" that can be easily reused in different simulations, are built along the same structure as the actual physical entities that are modeled. For example, a particular communication system may contain a digital data input device, a radio, a cable, an antenna, etc. The radio may be composed of a receiver, transmitter, digital signal processor, and message or packet processor. This decomposition leads to simplified hierarchical model products that can be easily modified for reuse in new simulations.

Under its SBIR Phase III Contract "Extensions to Expert System Simulator to Evaluate AI Techniques for Communications System ECCM," PSI used previously developed model products to incorporate into simulations of the Army's Mobile Subscriber Equipment (MSE) system. Under this ongoing contract, PSI is analyzing expert system approaches to Electronic Counter-Counter Measures (ECCM) for future use in the MSE System Control Center (SCC). These models have also been used in other analytical efforts by both PSI and other Government contractors. These models are easily shared among Government and industrial organizations. This is important, because the development cost of a model product can run into the millions of dollars. When built as a product, a model becomes a reusable asset for future use. This has been clearly demonstrated under the Army's SBIR program at Fort Monmouth. PSI has used commercially available simulation tools, including its own General Simulation System (GSS) and General Stochastic Analysis (GSA) system, developed privately in the late 1970s, to build the model products. PSI does not engage in end-item product efforts for the Government, but instead concentrates on research, development, and prototyping for both the Government and its production contractors. PSI provides both source code and documentation of the model products built under contract to its clients.

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Phase III Impact

- *ECCM has been sold to Government and commercial sectors*

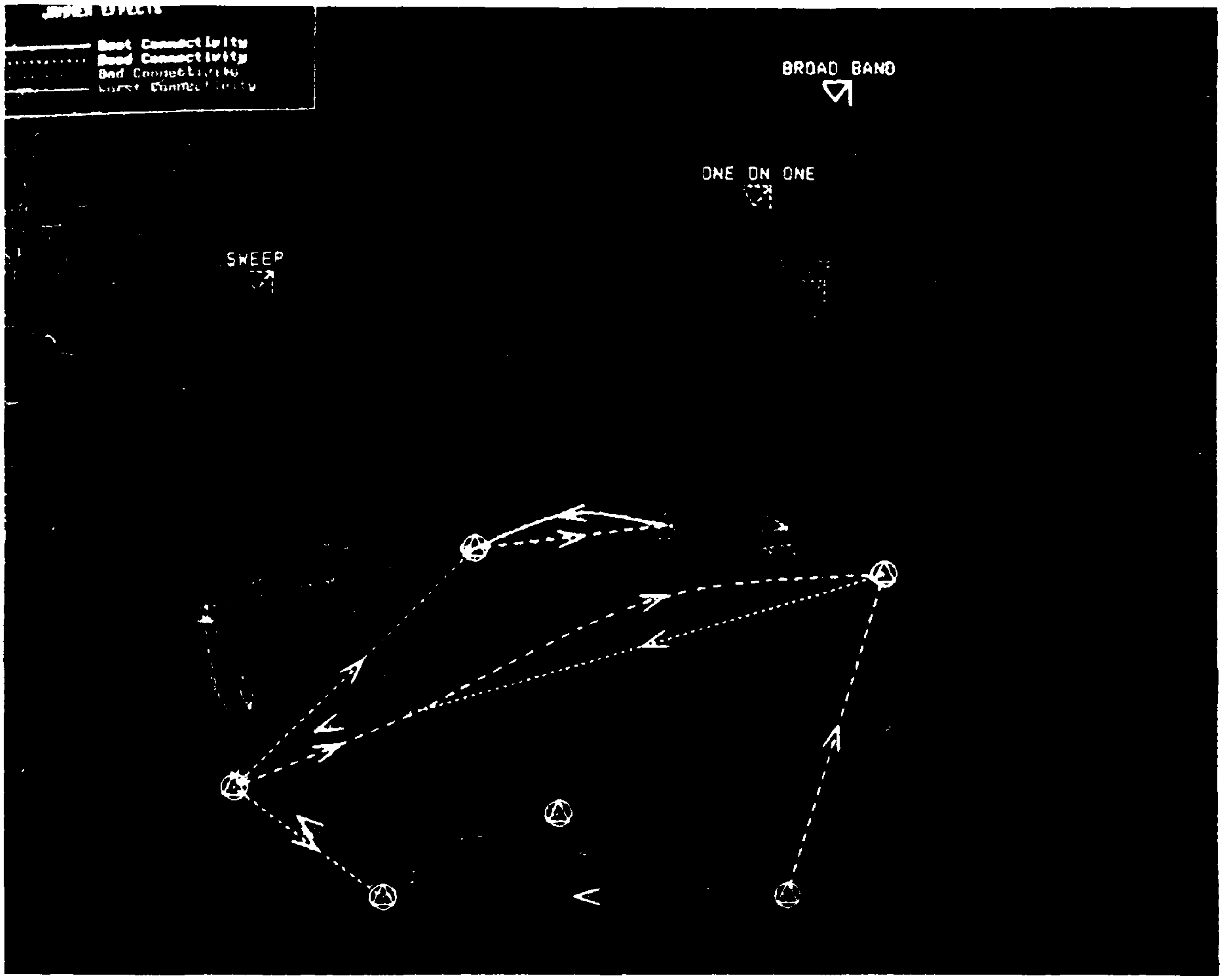

Figure 1
Sample Image Generated Using Prediction Systems' Simulation Model

Development of a Resin Applicator Ring for the Braiding of Composites

U.S. Composites was the first small business awarded a contract by the Materials Technology Laboratory (MTL) under the SBIR Program, and was the first Army-wide SBIR contractor to successfully reach Phase III.

U.S. Composites Corp. was founded in 1980 to manufacture improved products using advanced composite materials. We immediately became interested in the potential advantages of adapting textile braiding machines to the manufacture of composite structures: braids can readily conform to complex shapes, braiders are more precise than hand lay-up methods, and can operate at high production rates. Despite these advantages, braiders were seldom used for composites because they lacked numerical control and no one had found a viable means of applying the resin. Post-braiding impregnation resulted in high costs and poor quality. By 1983, we had invented a system which could solve the resin impregnation problem.

Known as the Resin Applicator Ring (RAR), our device proved to be unique and we therefore applied for a patent. However, we had exhausted our own funds, and were unable to raise venture capital since the RAR had not be demonstrated on a meaningful scale. To support our work, we applied to the Army Materials Technology Lab (Watertown, Ma) for a Phase I SBIR contract, and received a $23,500 award. The Phase I funding allowed us to test laser drilling as a means of producing the porous ring surface. The success of Phase I led to a $327,000 Phase II contract. Under Phase II, we built and fully tested the RAR system with computer controlled resin pumps on a 64 carrier braider. Later in the contract, we built a 450 mm bore RAR and installed it on a 144 carrier braider at the Benet Weapons Laboratory (Watervliet Arsenal). By 1986, we negotiated a Phase III license/commercialization agreement with DuPont, and our business with DuPont has grown many times over since then. Our staff has grown from 2 to 23 people, and we expect to grow at 30-40 percent per year.

The focus of the company's efforts has been to exploit the RAR to continuously impregnate moving fibers with resin in a controlled environment for the effective braiding of composites. Although braiding can be readily automated and offers high fiber deposition rates, geometric versatility, and significant potential manufacturing cost reductions, its use was previously limited due to difficulties in wetting fibers moving in a complex path. Employment of the RAR mitigates these problems.

The RAR was developed to adapt braiding to automatic production of advanced composites. A tubular braider was equipped with a computer numerical control system, and two axes are used to drive pumps that feed the resin and catalyst to the resin impregnation ring. The mix ratio and resin volume fraction, along with braider and mandrel speeds, are coordinated with software to fabricate parts with complex features.

Tubular specimens of fiberglass composites were prepared and tested to compare resin applicator ring versus conventional braiding. Properties for the resin applicator ring braided speciments were 24 percent greater in torsional strength and 29 percent greater in torsional modulus than conventionally braided specimens.

Potential structural applications for braided composites are vast within the Army and include helicopter and propeller blades, launch tubes, and lightweight bridging components. The potential advantage of effective manufacture of composite parts via braiding include high production rates, precise fiber orientation, net shape fabrication, superior damage tolerance, and cost savings of up to 40 percent along with quality improvements.

The first Army components fabricated to demonstrate the resin applicator were sub-scale trails for the Lightweight Howitzer. These were manufactured during October 1986 on a composite braider located at Watervliet Arsenal's Benet Weapons Laboratory, Watervliet, New York. The Army will retain possession of the full-scale production resin applicator ring that has been installed on the 144 carrier braider at Watervliet Arsenal's Composites Laboratory.

Redstone Arsenal of the U.S. Army Missle Com-

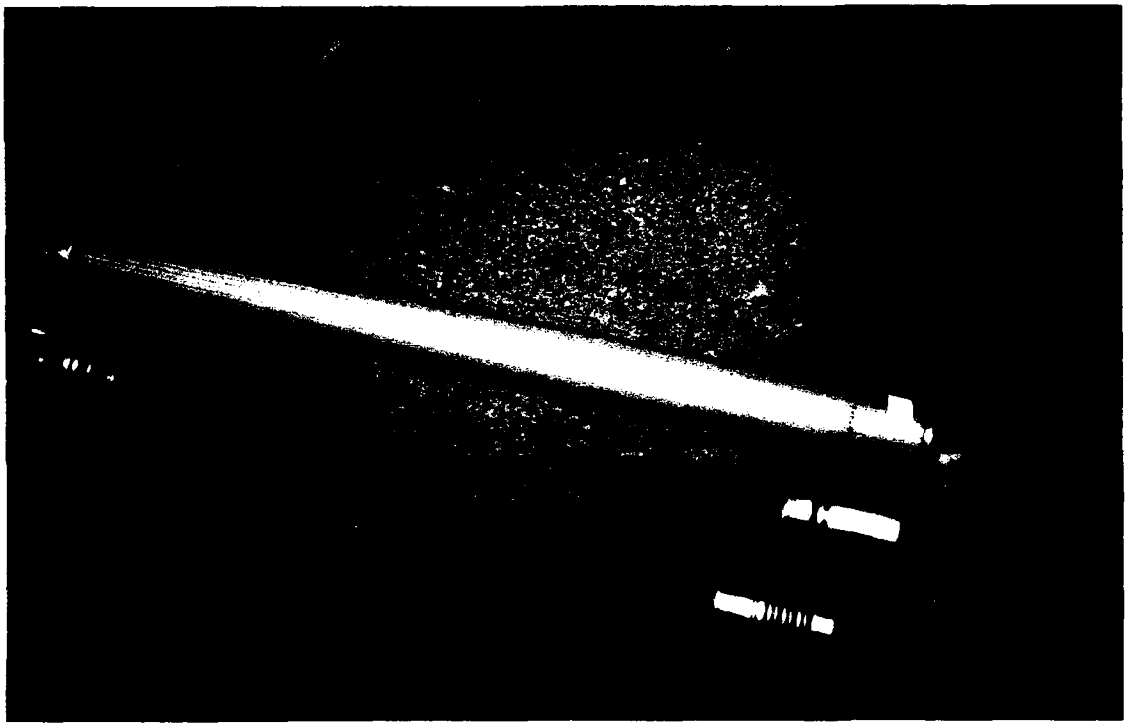

Figure 1
Braided 2.75 Inch Rocket Motor Case

mand, Huntsville, Al, has acquired a RAR system and plans to braid rocket tubes for anti-tank weapons. The U.S. Army Troop Support Command's Belvoir Research and Development Center, Fort Belvoir, Va., plans to employ the RAR system in fabricating lightweight bridging elements.

U.S. Composites has found many application for the RAR technology, both DOD and commercial. For example, we developed a 2.75 inch overbraided propellant rocket motor case to meet NAVSEA 8010.5 (Insensitive Munitions) requirements. We have sold RAR systems with computer controls to both Redstone Arsenal and the Naval Ordnance Station. We are currently developing and/or producing such diverse products as golf shafts, surgical tools, satellite structures, conformal gas storage hose, fiberoptic spools with tailored thermal expansion (e.g. FOG-M/NLOS), aircraft propeller spars and aircraft engine composite tubing. Recently, we were awarded another SBIR Phase I by the Air Force/NASP project office to braid carbon/phenolic preforms for carbon/carbon fasteners. We are now well on our way towards becoming a major industrial company. With patents in twelve foreign countries, we are in a good position to withstand global competition. The Army SBIR program was a key contributor to our success.

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Phase III Impact

- *Process has been patented in twelve foreign countries*
- *Sales to Government and private sector*

An Advanced Software Testing Tool

To exercise code, find failures, and demonstrate functionality, most programmers manually enter test case inputs into their software. Some programmers apply debugging tools which use inputs to run or exercise code. A few programmers employ regression testing tools such as capture playback programs which automatically rerun old test cases. All of these are acceptable ways of running test on software.

The goal of this SBIR project was to expand a prototype software testing tool, T, for use in larger computer systems. T is a software tool that automatically produces sets of input values (test cases) which are used to test programs or systems. It creates the high quality test cases that programmers must have to test effectively. T employs a knowledge base of the most probable errors and a set of rules for designing the minimum number of test cases that will exercise every function the software should perform and locate every most probable error.

T can automatically design test cases, or it can help its user design them in a computer-aided mode. T is helpful in all three activities of design. T groups action statements into sets so all actions in a set can be exercised using the same input values. This helps to minimize the total number of test cases needed. T chooses a few input values to be used in test cases from the set of all possible valid and invalid values of each input. The samples that are chosen have the highest probability of detecting failures. T selects combinations of input values. These combinations have the highest probability of identifying failures, showing functionality, and speeding debugging.

T designs test cases using several well-known techniques: functional testing, equivalence class partitioning, cause-effect graphing, boundary value analysis, random value selection, and experience-based testing. Since exhaustive testing is impractical on everything but the simplest software, T does not attempt to design an exhaustive set of test cases. Instead, T creates just enough high quality test cases to assure 100 percent functional coverage and 100 percent most probable error coverage.

T supports test execution by providing an on-line, pass/fail recording facility. With it, the tester can specify test case priorities and record dates of execution and pass/fail results. This information is essential in evaluating the software and test cases. T evaluates test effectiveness by automatically calculating Testing Comprehensiveness (TC). From the recorded pass/fail information, T reports requirements and input and output coverage in both tabular and graphical form. Structure coverage is accounted for in TC.

A unique and powerful feature of T is its batch or script interface that allows a user to leave the computer while T continues to work. Testers are free to go home at night knowing they will return in the morning to find high quality, documented test cases awaiting them.

T runs in many different environments. It works as a single-user tool on the IBM PC-AT running MS DOS where it requires 300 kbytes of main memory, 2 megabytes of hard disk, and a 1.2 megabyte floppy disk. T also works in multi-user Unix environments on AT&T, DEC, Sun, Hewlett-Packard and SEL computers. A VAX VMS is also available.

A study that was conducted at Ft. Sill showed that use of T resulted in a cost savings of up to 60 percent. The product has been endorsed by the AFATDS Project Management Office at Ft. Monmouth, N.J. Programming Environments is pleased that this project has resulted in cost savings to the Army prior to completion of Phase III. Programming Environments has successfully commercialized this software tool, and has recently conducted T training sessions for a host of companies including 3M, AT&T, College of William and Mary, Shell Oil Co., Ford Aerospace, and GE.

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Phase III Impact

- *Endorsement by the AFATDS Project management office, Ft. Monmouth, NJ*
- *Commercialization and sales to numerous major corporations*

Human Knowledge Engineering

In 1985 the Army Research Institute for Behavioral and Social Sciences awarded Klein Associates a Phase I contract under the SBIR program. We were to investigate how proficient decisions makers can function under high degrees of time stress. In the course of this contract, Klein Associates developed a theoretical model which describes time-pressured decision processes and a method of eliciting information which reveals how experts make decisions.

In Phase I we studied how proficient decision makers function under high degrees of time stress by interviewing fireground commanders, the people in charge of putting out fires in urban settings. Typically, they make tactical decisions, e.g., about allocating resources and personnel, in less than a minute. We used semi-structured interviews and special cognitive probes to ask the fireground commanders about difficult and nonroutine fires and learn their strategies. The decision model coming out of this research differed from the standard descriptions of decision making. The findings became the basis of two subsequent research contracts, covering six years and more than $500,000.

We designed the SBIR Phase II contract for further development of our method for knowledge elicitation, or "getting inside the heads," of the fireground commanders. We wanted to expand, formalize, evaluate, and apply the method in Army situations. We named the interview technique the critical decision method (CDM) because the focus is on probing how people make difficult and challenging decisions (see Table 1). During Phase II, the CDM was used to study the decision making of Army tank platoon leaders, Army battle commanders, and incident commanders in charge of forest fire operations. We also expanded the CDM and the model to describe the team decision making as well as individual performance.

By the end of Phase II, we had established the CDM as a strategy for capturing expertise. We had also identified a commercial market: organizations seeking to preserve their corporate expertise. When we think of the resources of an organization, we think of equipment, building, and land—but often overlook the expertise of the people who work there. This expertise can be lost when workers move on. The CDM is a technique that can be used to elicit expert knowledge, so as to preserve it and make it available to others.

Probe Type	Probe Content
CUES	What were you seeing and hearing?
KNOWLEDGE	What information did you use in making this decision, and how was it obtained?
ANALOGUES	Were you reminded of any previous experience?
GOALS	What were your specific goals at this time?
OPTIONS	What other courses of action were considered, or were available to you?
BASIS	How was this option selected/ other options rejected? What rule was being followed?
EXPERIENCE	What specific training or experience was necessary or helpful in making this decision?
AIDING	If the decision was not the best, what training, knowledge, or information could have helped?
TIME PRESSURE	How much time pressure was involved in making this decision?
SITUATION ASSESSMENT	Imagine that you were asked to describe the situation to a relief officer at this point, how would you summarize the situation?
HYPOTHETICALS	If a key feature of the situation had been different, what difference would it have made in your decision?

Table 1
Critical Decision Interview Probes

Although another company had expressed willingness to provide Phase III funding, we decided upon the completion of Phase II that the CDM could be directly commercialized. In the next year, Klein Associates applied the CDM in varied settings.

1. The introduction of new technology and treatments in critical care requires that healthcare providers share newly gained expertise as rapidly as possible. The National Institutes of Health funded research to identify the cues which warn experienced nurses of life-threatening problems with premature infants. We used Critical Decision interviews with nurses at Dayton's Miami Valley Hospital to elicit their knowledge and expertise in patient assessment.

2. We conducted Critical Decision interviews with 20 of the best program managers and scientists at the Air Force Wright Research & Development Center to capture their expertise in conducting effective programs and projects in a bureaucracy. Our descriptions of their success stories will be shared with scientists and engineers.

3. We interviewed expert programmers to develop the content and materials of a training course for Bell Labs. We used the CDM to assist AT&T software experts in describing how they visualize software problems and develop troubleshooting, or "debugging," strategies.

The extension of the CDM and the model to cover team decision making has been valuable in two projects. Our descriptions of crew problem solving during emergencies may assist in designing advanced cockpits. Working with the NASA Ames Research Center, we examined communications among three-man crews of a commercial Boeing 727 during training flights with simulated malfunctions. We used the CDM to represent team decision strategies at the Central Training Academy, a facility sponsored by the Department of Energy for training nuclear production personnel to manage emergencies. As part of the Academy's ongoing crisis management course, we have provided a block of instruction on team decision making.

The Phase I effort generated both a new theoretical perspective on decision making and a new methodology for studying expertise. Phase II enabled us to expand the methodology, evaluate it, and demonstrate its applicability. Commercialization of the CDM developed under the SBIR program resulted in a valuable product that has been widely used. We now have an experienced group of professionals within the company with a central mission to conduct knowledge engineering in a variety of settings and applications.

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Phase III Impact

- *Projects with NASA, Department of Energy, and other Government agencies*
- *Commercialization and numerous sales to the private sector*

Improved Ceramic Magnetic Materials

ETDL recently transitioned the technology developed under a highly successful SBIR program into a technology transfer program via a Cooperative Research and Development Agreement (CRDA) as allowed under the Technology Transfer Act of 1986.

This SBIR effort by Electromagnetic Sciences, Inc. resulted in an improved class of ceramic magnetic materials (ferrites, much like "refrigerator" magnets) for millimeter wave devices (i.e., high frequency switches), which utilize these materials for performing circuit functions such as signal switching and electronic antenna scanning in radar and communication systems.

This development has impacted DOD and NASA radar and communication systems. The DOD's MILSTAR program has used these ferrites in military communications satellites. NASA's advanced communications technology satellites (ACTS) utilize ferrite switches and isolators, as do the NASA COBE satellites. The new ferrite material is also in DOD's 94 GHz network, NASA's AMSV radiometers, and numerous other programs.

The participants in the follow-on CRDA are ETDL and Electromagnetic Sciences, Inc., the SBIR contractor. The CRDA covers the test and evaluation of these millimeter wave ferrite materials and associated devices under high power operation and is now being carried out in ETDL's high power millimeter-wave test and evaluation facility located in the newly completed Pulse Power Center. This effort will aid in the development

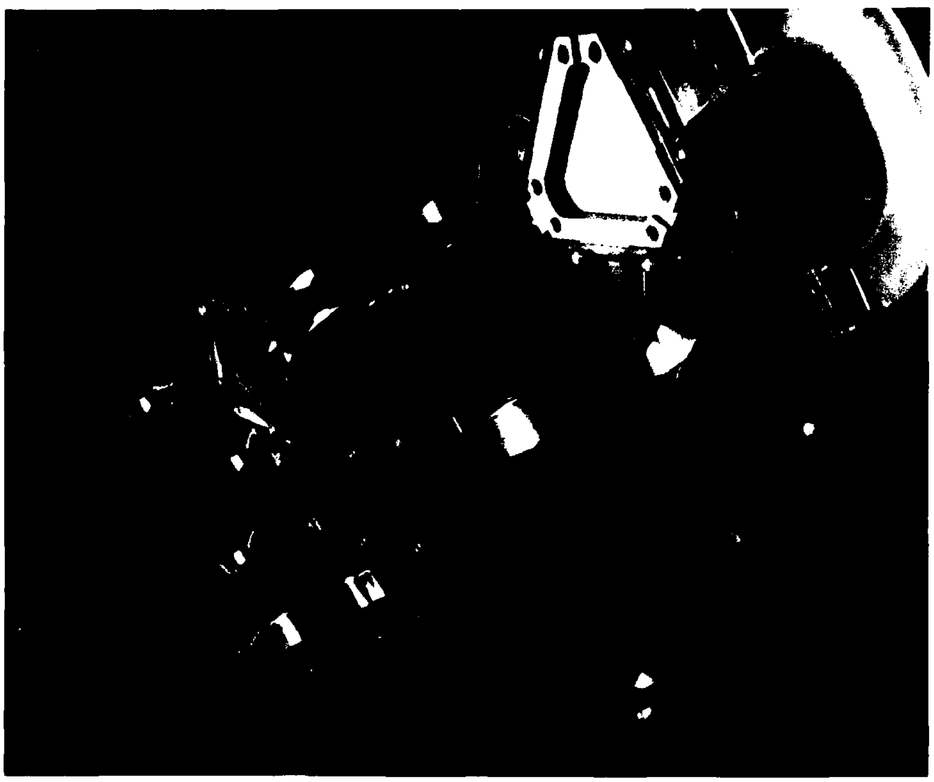

Figure 1
The 20/30 GHz Beam Forming Network Used in the NASA ACTS Antenna System

of devices capable of withstanding the power requirements in new radar and satellite communication systems for future military/commercial applications.

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Phase III Impact

- *Materials used in many NASA programs*
- *Widely used by DOD and other Government agencies*

Advanced Howitzer Integrated Technology

Odetics Inc. has been contracted by the SBIR Office and the U.S. Army Armament Research, Development and Engineering Center (ARDEC) at Picatinny Arsenal to design and build an automatic ammunition and propellant handling/loading system for Army's AHIT system. AHIT (Figure 1) is a testbed for an automated Howitzer under development by ARDEC. The autoloader is expected to be demonstrated in 1991, and will use a new propellant charge (unicharge).

The autoloader system will provide significant improvements to firing rates and manpower requirements by automating the storage, retrieval, and loading of both projectiles and propellants. The system objective was to receive a fire mission, verify inventory, place the system into ready position, and to load and fire at a maximum burst firing rate of four rounds in fifteen seconds upon command. Due to the automation capabilities of the system, sustained firing rates can be met with improved safety due to supervisory control and reduced crew fatigue.

The autoloader system is being designed to handle 155 mm artillery projectiles and unicharge propellants. The system consists of modular subsystems: the magazine, the transfer mechanism which includes the rammers, the power converter, and the controller. The system will be all electric to permit utilization of advanced motors, drivers, and electronics currently available in industry.

The magazine will store both projectiles and uni-

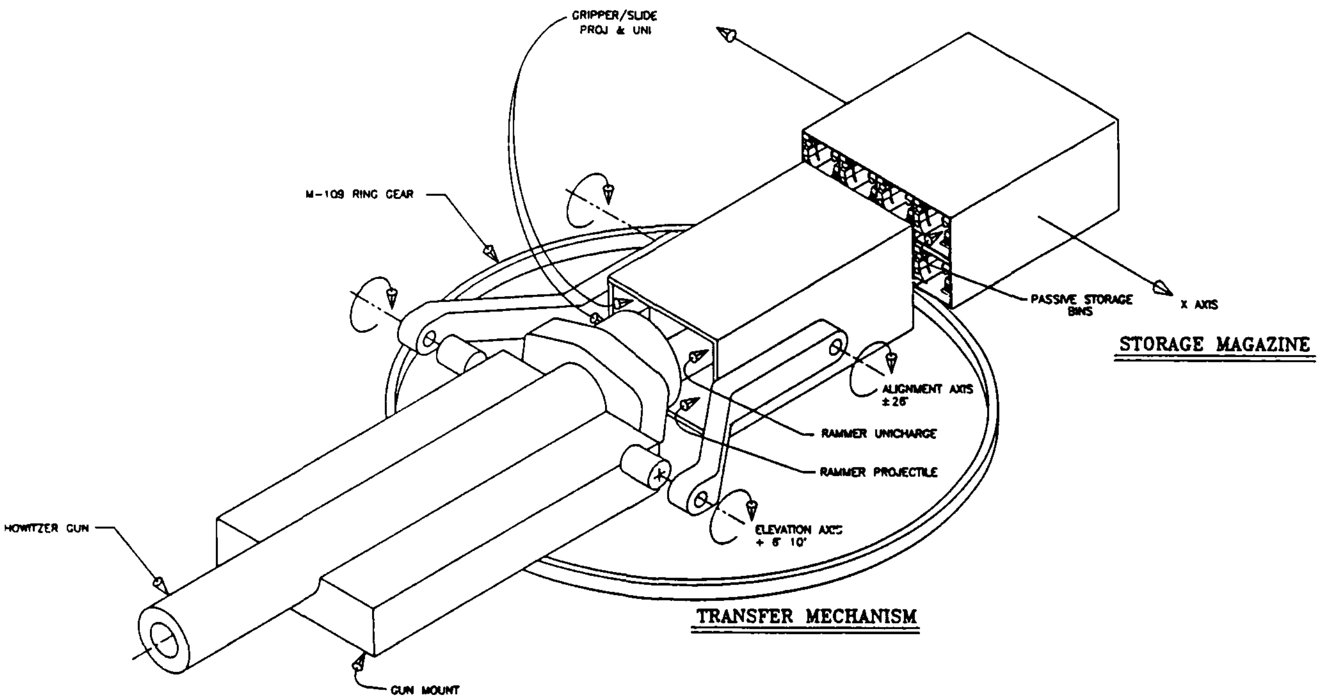

Figure 1
The AHIT 155mm Autoloader

charges in a secure manner and locate them for retrieval by the transfer mechanism. The transfer mechanism will remove the projectiles and unicharges from the magazine utilizing a gripper slide that will positively constrain and transfer without sliding the payloads. Once the ammunition is in the transfer mechanism, the mechanism aligns itself with the gun, bridges the gap between the gun and mechanism utilizing the gripper slide, and rams the projectile and unicharge respectively into the gun chamber. Independent rammers are utilized during the loading of the projectile and unicharge into the gun chamber. The projectile rammer performs a flick operation wherein the projectile is accelerated to a determined velocity and travels through the gun chamber until it lodges in the forcing cone. The unicharge rammer pushes the unicharges into the gun chamber and insures the engagement of the last unicharge into the gun's swiss notch. The transfer mechanism returns to the storage magazine for retrieval of the next set of munitions while the gun breech is closed and the gun fires. This process takes place at the burst firing rate and at a slightly reduced rate for continuous operation.

In support of the retrieval, transfer, and loading subsystems, a specifically developed power subsystem is necessary to regulate the power surge requirements and reduce to a nominal level the overall system power requirement. The controller subsystem utilized was developed under an SBIR contract and will control the system functions of timing, mode control, actuator control, inventory management, system status, system safety verification, diagnostics, and operator interface.

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Phase III Impact

- *Competitive Phase III contract awarded by ARDEC*

Scanning Tunneling Microscope

There is a growing critical need, both in military and commercial areas, for systems capable of imaging and probing structures with submicron feature sizes. Semiconductor feature sizes are currently decreasing from one micron dimensions to submicron dimensions. Even devices using single molecules for logic functions are under study. Using funds from the SBIR program, QuanScan developed a scanning tunneling microscope that is capable of delineating features as small as .001 microns. Unique attributes of this product are a built-in optical microscope, integrated vibration isolation, and a high resolution two dimensional translator. QuanScan's scanning microscope is used in Government, university, and industrial development laboratories throughout the United States.

A recent development in instrumentation has made possible the nondestructive, noncontact measurement of surface topography to unprecedented resolutions. These instruments are based on the interaction of a sharp probe and the sample surface, and are called Scanning Tunneling Microscopes (STM).

STMs are based on the quantum mechanical tunneling of electrons from a sharp metallic electrode (the tip) to a second electrode (the sample) under an applied electric field. The sample is usually stationary while the tip is scanned over the sample. The tip is mounted on piezoelectric ceramic materials (materials which change physical dimensions upon excitation by an electric potential), and is capable of moving in the x, y, and z directions by the application of electric fields to the ceramics. The ceramics are capable of high resolution movements from 10^{-3} microns to 100 microns.

A feedback loop is used to maintain a constant tip-sample spacing while the tip is being scanned over the surface. A block diagram of the STM feedback is shown in Figure 1. The feedback electronics operate in four

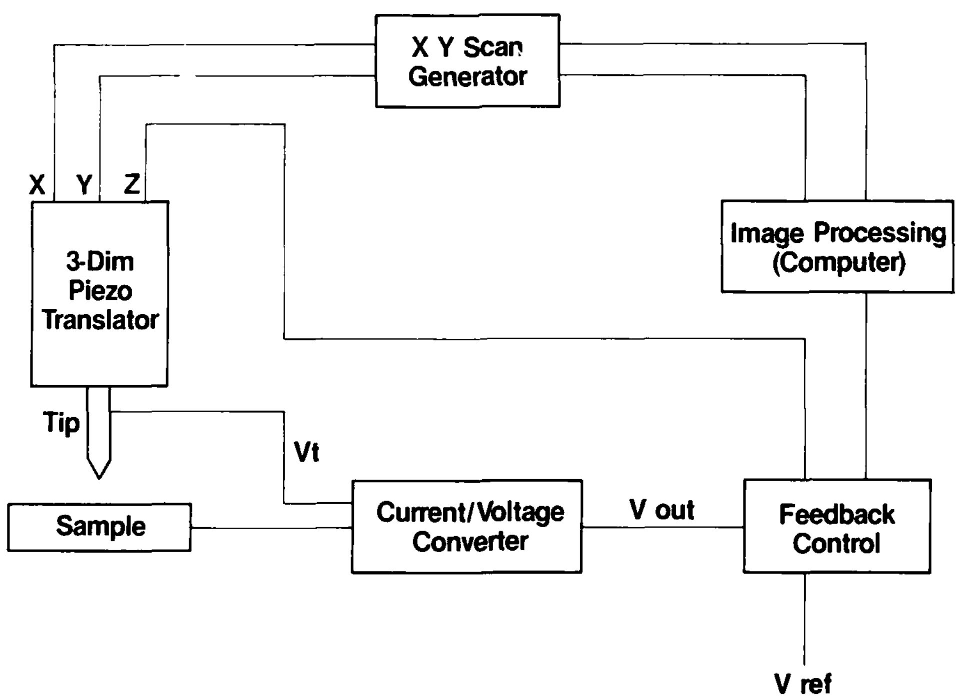

Figure 1
Block Diagram of STM Feedback

Figure 2
Commercial STM Developed by QuanScan under SBIR Program

steps. Under an applied voltage to the tip, the electrons tunnel from the tip to the sample resulting in a current flow. A current-to-voltage converter outputs a voltage, V_{out}, which is proportional to the tunneling current. V_{out} is then compared to a reference voltage, V_{ref}, in the feedback control unit. The output of the feedback control unit activates the z-direction piezoelectric ceramic which maintains a constant tip-to-sample current.

After the tip is brought into a feedback position near the surface, it is scanned using the x-and y-direction piezoelectric ceramics. The tip maintains a constant distance (constant current) from the sample as it follows the contours of the surface. The voltage (V_{out}) to the z-direction piezoelectric ceramic, which is used to maintain a constant tip-to-sample spacing, is now proportional to the topography of the surface. The image is digitized and stored in the computer for further analysis. The vertical resolution of the instrument is due to the strong dependence of the tunneling current on the tip-sample spacing.

Scanning probe microscopy permits the submicron imaging of surface features in ambient air and liquids. Figure 2 illustrates the commercial STM developed under the SBIR program and manufactured by QuanScan. It is comprised of a personal computer, an electronic control unit, and a microscope stage.

The scanning probe microscope is ideal for measuring the dimensions of submicron features created by lithographics techniques. As an example, Figure 3 illustrates an STM image of quantum dots fabricated from gold deposited on silicon (image courtesy of Texas Instruments).

Another useful application for the STM is imaging metal coated semicodutors to observe the sizes of grains. Figure 4 illustrates the image of grains in a silicide.

The microscope developed under this SBIR program has several unique features. The integrated optics permit the user to locate a specific region on a sample to be scanned and display the image on a video monitor with powers of 100×, 150×, and 200×. An automated

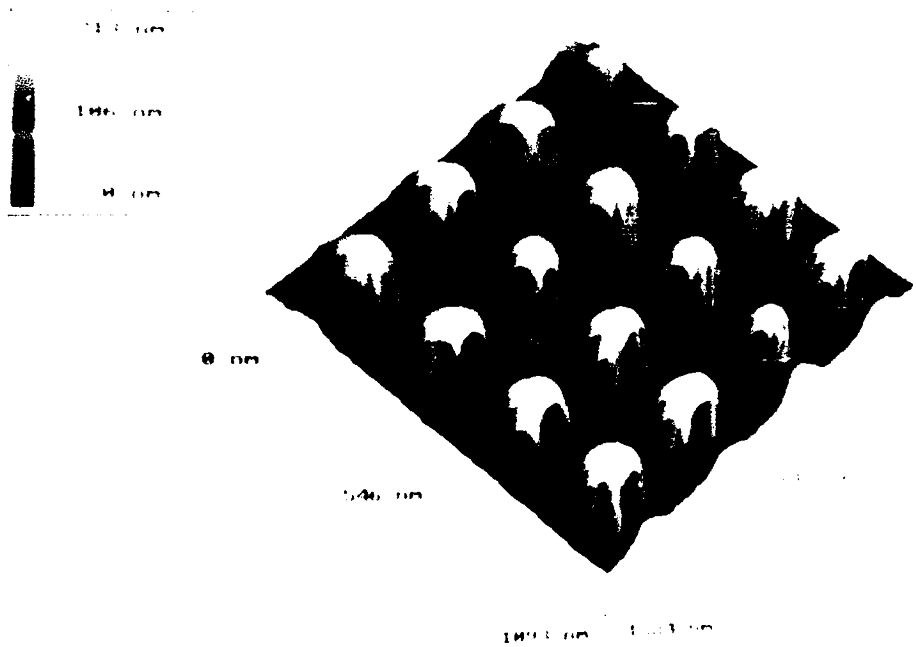

Figure 3
STM Image of Quantum Dots Fabricated from Gold Deposited on Silicon

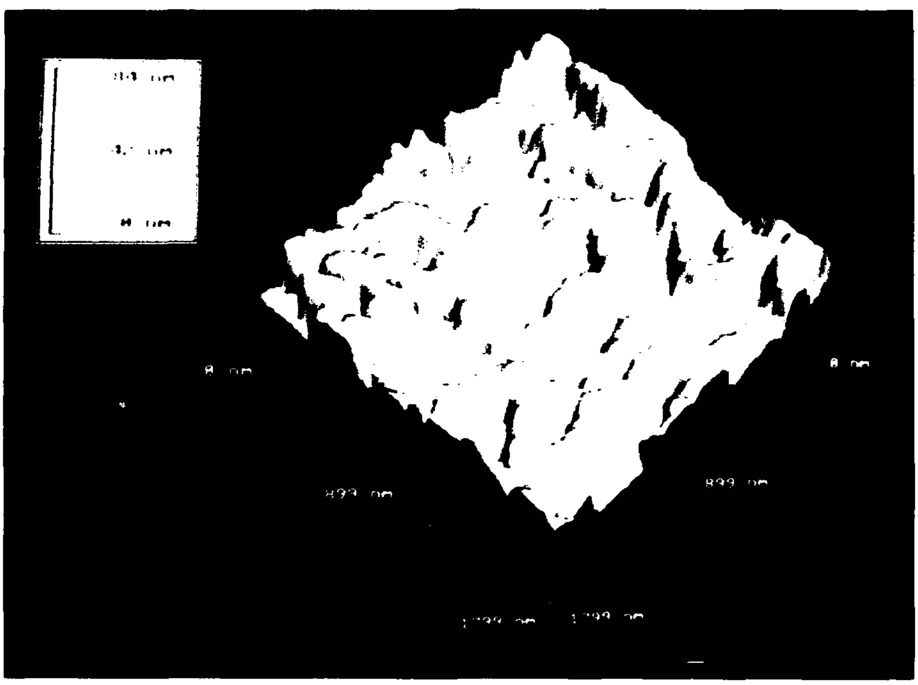

Figure 4
STM Image of Grains in a Silicide

x-y translation stage has a 1 × 1 cm range and a resolution of 1 micron. A scan area can be user selected via the computer keyboard from .0001 × .0001 microns up to 100 × 100 microns. Images can be displayed in several 3D formats. The precise dimensions of surface features can be displayed from linescans.

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Phase III Impact

- *Sales to Government, university, and industrial development laboratories throughout the U.S.*

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